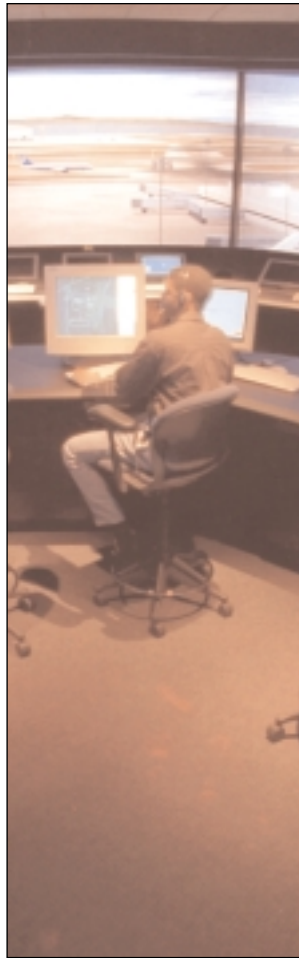
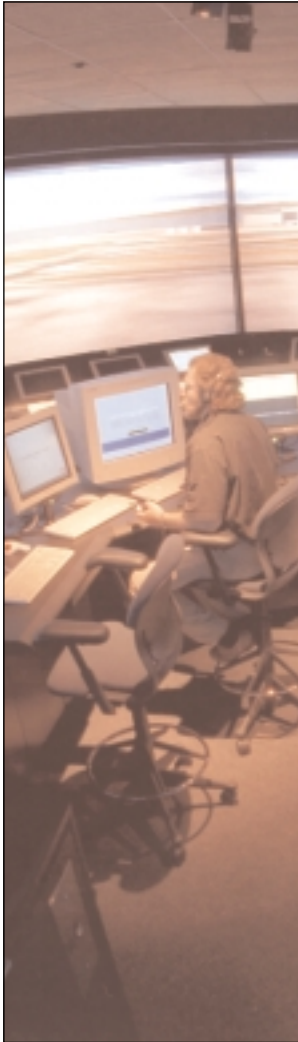


NASA & The FAA



A Technology Partnership for the New Millennium

*Brief Descriptions of Aviation Research and Technology
Programs and Projects from the Federal Aviation
Administration and the National Aeronautics and
Space Administration*



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A Technology Partnership for the New Millennium

Aviation has been one of the most important enterprises in the U. S. for nearly a century. It developed out of the early vision and determination of a few dauntless experimenters to become the main service of large corporations that move people and goods; others are dedicated to the manufacture of aircraft built to the most demanding specifications to assure predictability of performance. Today, the U. S. is recognized as the world leader in aviation based on the combined efforts of industry, academia and government.

The role of the Federal Aviation Administration (FAA) in this activity is to safeguard public safety, security, efficiency, and protection of the environment through the issuance of guidelines, advisories, and regulations. Additionally, the FAA provides safe and efficient air traffic control and flow management services. NASA's mission in part is to research, develop, verify, and transfer aeronautics and related technologies. NASA research focuses on advances in high-risk revolutionary technologies that are needed to maintain the U.S. preeminence in aeronautics. The continuing need for modernization,

growth, and realizing new transportation opportunities present formidable challenges, which both agencies can overcome by working in close cooperation to leverage each other's strengths. By integrating research and development activities, we are developing innovative technologies, concepts, and products that will fill the needs of a dynamic industry.

This booklet describes examples of the research and development projects being performed by the NASA and the FAA to realize our objective of providing products and operational concepts that will make today's aviation system more safe, secure, efficient, and environmentally friendly.

When viewed together, these research directions begin to reveal an exciting future for air transportation. However, this future can be achieved only through the cooperative efforts of the entire aviation community. We look forward to your involvement and help as we build an understanding and commitment for Federal investment in science and technology, and forge the government-industry partnerships required for success.



Because of the continued vigilance of state and federal aviation officials, airline companies and airport operators, the commercial aviation accident rate has been nearly constant and quite low for two decades. We have come a long way in creating a safer aviation system for today and tomorrow. More technological advances are needed however, to prevent a rise in accidents if air traffic more than doubles as predicted by 2017.

Not only does the Federal government need advanced technologies to meet the national goal to reduce the fatal aircraft accident rate by 80 per cent in ten years, it also needs the continuing help of its aviation partners. In the 96-year history of human powered flight, one of the biggest strengths of American aviation has been the partnership among state and federal governments and the private sector. This partnership has proven effective in the past and will help lead us into the future. Cooperation and coordination is especially important as demands increase and resources decrease worldwide.

The FAA and NASA have already formed an alliance to develop technologies that will maintain and improve safety in an evolving and demanding aviation environment. Improvements will reduce fatalities and injuries, improve airport safety, reduce aircraft losses, help create better aircraft and airport designs, and improve maintenance and inspection procedures. Working with industry, other federal agencies, academia, and state governments we will be able to put new safety technology on the ground and in the air to meet the challenges of aviation in the 21st century.

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1.1 Aviation Weather Information (AWIN)

Between 1982 and 1993, 5,894 weather-related general aviation accidents were reported. These resulted in 1,750 fatalities. During a similar period (1983-1995), the National Transportation Safety Board identified weather as a causative factor in 112 commercial aviation accidents and incidents, leading to 13 fatalities, 58 serious injuries, loss of 8 aircraft and substantial damage to 34 others. Annual losses associated with weather-related accidents are in the hundreds of millions of dollars.

The Aviation Weather Information (AWIN) Project created a government-industry-academia team to develop prototype systems for detecting and avoiding atmospheric hazards. This team assembled diverse technologies for weather sensing, forecasting, communication, and displays. These technologies will provide accurate, timely, and strategic weather information to the pilot, and also to dispatchers and controllers for collaborative decisionmaking.

This original and innovative system uses both ground-based and satellite infrastructures to deliver graphical weather information. It also boasts several technical achievements, developed in a record two-year period. The prototype systems for both commercial transport and general aviation airplanes were flight demonstrated, and the user feedback is being incorporated into a second generation of prototype cockpit displays.



A commercially viable Aviation Weather Information (AWIN) system will enhance pilot awareness of weather phenomenon, decreasing the accident rate where weather is a contributing factor, while increasing efficiency due to better reroute decisions.

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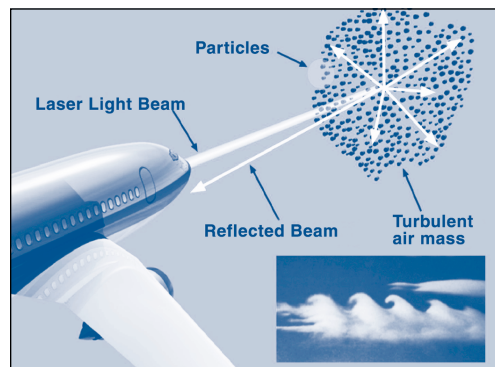
<http://AWIN.larc.nasa.gov>

1.2 Turbulence Detection and Mitigation Research

Atmospheric turbulence is the leading cause of in-flight injuries to passengers and flight crews. FAA statistics show that 98 percent of those injuries happen because people aren't wearing seat belts. An alert of impending rough air would give pilots time to warn passengers and flight attendants to buckle up and take steps to reduce turbulence effects. Not only is turbulence hazardous: it also costs the airlines time, in the form of re-routing and late arrivals, and money, an estimated \$100 million a year.

Turbulence is often associated with visible storm systems. Aircraft can use available radar systems to detect and avoid that particular form of rough air. But currently there are no effective systems to warn flight crews of clear air turbulence, which generally occurs at cruising altitudes.

A NASA-industry team has already flight tested a sophisticated laser device which was able to sense previously undetectable clear air



Detecting nonvisible turbulence with a laser light beam will provide pilots valuable seconds for warning crew and passengers and taking safety precautions.

turbulence. The Airborne Coherent Lidar for Advanced In-flight Measurement (ACLAIM) project came out of technology developed for a high speed civil transport.

Work is also underway to better understand and predict clear air turbulence and develop reliable and effective detection and mitigation concepts. This goal requires:

- ◆ Development of highly reliable detection technology to sense dangerous turbulence with sufficient warning to institute defensive maneuvers
- ◆ Improved resolution of forecasts to provide advance prediction of turbulence, which would reduce the frequency of encounters
- ◆ Development of rough air encounters technology, which would reduce or alleviate dangerous turbulence effects

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1.3 Project SOCRATES (The FAA's Wake Turbulence Research Program)

When weather forces marginal VMC or IMC operations, many airports currently experience congestion, which impacts safety and causes costly delays. Improvements in navigation and surveillance technologies and procedures can safely provide the needed efficiency gains, provided that constraints due to wake turbulence can be accommodated. Project SOCRATES is the current FAA program for developing the wake turbulence safety net and standards required for application of the new technologies. The initial focus is on capacity issues and safety at airports with closely spaced parallel runways. Airports with closely spaced parallel runways routinely use both runways for VMC



operations. In IMC, closely spaced runways less than 2500 feet apart are operated as a single runway due to wake turbulence constraints. This severely reduces capacity and frequently causes extensive delays, which may extend throughout the system. For example, United Airlines has stated that delays at San Francisco cost \$100 million per year.

There is general agreement that new runways with greater separation are the most effective solution to the capacity problem. However, this may not be feasible due to airport space, cost, or environmental constraints. Current research initiatives to allow better utilization of closely spaced runways in IMC include SOIA (Simultaneous Offset Instrument Approach), ATS (Along Track Separation), paired approaches using ADS-B technology, and NASA's AILS (Airborne Information for Lateral Spacing) Program. Implementation of any of these technologies for runways less than 2500 feet apart requires a reassessment of current wake turbulence constraints. The initial focus of Project SOCRATES is to define appropriate wake turbulence constraints and thus enable the implementation of safer and more efficient technologies and procedures. A wake monitoring system has been installed at SFO to gather data required to validate models of wake motion and decay characteristics. The wake models and data will be used to propose operational wake turbulence standards. The research is integrated with NASA's AVOSS wake avoidance technology.

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1.4 Wind Shear Sensing Systems: An FAA/NASA Success Story

A meteorological phenomenon known as a "microburst" can occur in or near thunder-

storms and is often responsible for a particularly nasty form of wind shear. This wind shear can cause large and small aircraft alike to lose control and crash with little or no warning. Reactive systems are not capable of giving advance notice of wind shear. They alert the flight crew after wind shear is encountered. Following this warning, the crew can then take corrective action to avoid contact with the ground.

Between 1964 and 1985, over 25 U.S. airline accidents, 625 fatalities, and 200 injuries were caused by wind shear. In addition to new training and weather-avoidance procedures, the FAA in 1988 mandated that airlines install wind shear warning devices or wind shear predictive systems by the end of 1993. NASA scientists at Langley Research Center worked with several avionics and airline industry representatives to develop predictive systems for wind shear avoidance. The systems that resulted from this work provide 10 to 60 seconds of warning when wind shear conditions exist in the flight path—adequate time for the flight crew to maneuver around or safely through the hazardous wind shear condition. A system has been commercialized by a U.S. equipment manufacturer and was first incorporated by Continental Airlines.

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1.5 FAA Aviation Weather Research Program

The FAA has established an Aviation Weather Research Program (AWRP) to address specific requirements for weather-related support to aviation:

- ◆ Providing the capability to generate more accurate and accessible weather observations, warnings, and forecasts
- ◆ Increasing the scientific understanding of atmospheric processes that result in aviation weather hazards

The AWRP strategy focuses on requirements that reflect the weather information priorities of the aviation community and on conducting applied research to solve operational weather problems where targeted research can make a difference. Working in concert with the FAA's Weather Requirements Division, the AWRP will base its direction and efforts on the operational problems that need to be solved.

The AWRP is structured to perform the research work using a team approach. There are currently nine meteorological product development teams (PDTs), each targeted toward solving specific prioritized operational weather problems. Each PDT has developed a detailed 7-year work plan that includes collaboration and leveraging to the maximum extent possible. Each plan also shows how the results of the team's research will be made available to aviation users, such as by implementation onto National Airspace System (NAS) or National Weather Service (NWS) platforms or



by technology transfer to industry via cooperative research and development agreements.

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1.6 Aviation Digital Data Service

Accurate, timely and user-friendly forecasts of icing, turbulence, thunderstorms, and clouds are required to support flight operations. The FAA's Aviation Weather Research Program (AWRP) is funding the Aviation Gridded Forecast System (AGFS) PDT to conduct applied research and development of state-of-the-art forecasts of these variables. The Aviation Digital Data Service (ADDs) enables aviation decision-makers (e.g., pilots, airline dispatchers, automation systems) to easily and inexpensively acquire graphics, text, and grids of the latest weather observations and forecasts of icing, turbulence, and thunderstorms.

The first version of ADDs is being operated and maintained by the National Weather Service (NWS) Aviation Weather Center in Kansas City, Missouri. This version enables users to access standard and experimental aviation weather information in graphic,

gridded, and text formats. Included in the experimental information are forecasts of clouds and turbulence.

The second version of ADDs (which was implemented near the end of FY 99) generates graphical forecasts of icing, turbulence, clouds, and thunderstorms for specific flight routes requested by users, giving a vertical cross section of all altitudes.

Benefits to the aviation community:

- ◆ ADDs is a very cost-effective method of enabling aviation decision-makers and automation systems to acquire up-to-the-minute weather observations and state-of-the-art forecasts
- ◆ The digital format of ADDs facilitates interaction among computers, a key requirement to support free flight.

ADDs can be accessed by:

<http://adds.awc-kc.noaa.gov/>

Ceiling and Visibility

Marine stratus is the trapped cool and humid air from sea breezes. In the San Francisco Bay area, marine stratus causes frequent low ceilings at San Francisco International Airport (SFO). During these events, the airport cannot use independent parallel approaches and it must impose delay programs to regulate arrivals. SFO has the highest number of imposed delay programs of airports in the United States. Marine stratus is also a problem at other major coastal airports.

Failure to forecast accurately the times of onset and burnoff of marine stratus results in significant costs to the NAS. TMU delay program decisions, based on current forecaster capabilities, err in both directions: holding patterns result from failure to impose or maintain a needed program, and unnecessary delays result from failure to cancel an unneeded program.

Operational analysis shows that most of the unnecessary delay and a significant portion of the holding could be eliminated if the TMU were provided with accurate one-hour forecasts of the times of onset and burnoff of marine stratus. The approach taken is to improve the forecasting capability of the CWSU by providing additional weather



information that scientists have identified as critical for better forecasts and also to provide an automated forecast guidance system.

Although FAA efforts to date have concentrated on specific airports that suffer air traffic delays from reduced ceiling and visibility, there is also significant impact at the national level. Studies to date show that although the greatest benefit is from accurate 1-4 hour forecast products, improvement in underlying technologies may also lead to improved skill in forecasts of up to 12 hours. Beginning in FY01, AWRP is pursuing capabilities for forecast products to alleviate the impact of low ceiling and poor visibility across the National Airspace System. The weather products envisioned will forecast up to 12 hours ahead of the ceilings and visibilities during instrument meteorological conditions on a national level.

Benefits to the aviation community:

Studies indicate that up to one quarter of the summer delay at SFO would be eliminated by an accurate one-hour forecast of the time of burnoff. A successful product would provide savings of approximately \$7M per year at SFO. In addition, the techniques developed will provide the foundation for ceiling and visibility products for several other high-impact coastal airports. Finally, the national ceiling and visibility product will improve safety across the NAS, especially for general aviation users.

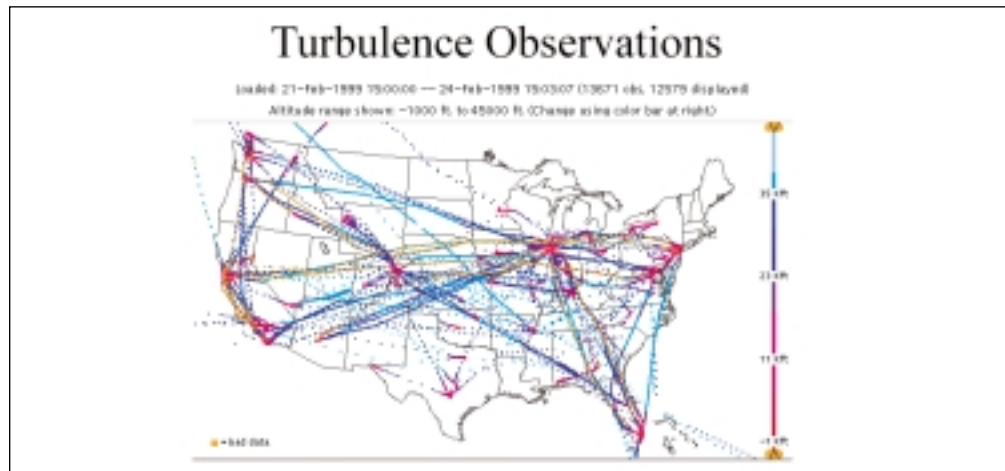
Turbulence

Clear-air turbulence is hazardous to passengers, crew, and aircraft, and is the number

one cause of injuries in non-fatal plane accidents. Unexpected encounters with severe turbulence can cause injury and sometimes death to those on board, as well as structural damage to the aircraft. Avoidance of light and moderate turbulence results in a more comfortable ride. Current forecast products give a broad view in time and space. Large regions that potentially contain turbulence are overwarned. Forecasts are made every 6 hours, and updates are triggered by pilot reports of significant turbulence; however, pilot reports are few, subjective, and sometimes ambiguous with respect to location and time of event.

Research sponsored by the FAA's Aviation Weather Research Program (AWRP) is investigating new methods of detecting turbulence, developing better algorithms and systems for 1 to 9 hour forecasts of turbulence, and establishing innovative techniques for disseminating these products.

The AWRP has developed an on-board (in-situ) algorithm which has been approved by ICAO as an international standard and integrated into the ACMS software of commercial aircraft. This algorithm provides objective turbulence measurements, which will be downlinked for use by forecasters at the AWC and will also be used for AWRP research into enhanced forecasting models. This algorithm has been installed on several United Airlines 737's and 757's and is undergoing validation and verification. Once this is complete, the algorithm will be installed on additional airframes and airlines to provide a broad automated turbulence reporting capability.



Detailed maps of turbulence in three dimensions are necessary for strategic and tactical route planning. Frequent updates to these forecasts permit refinement of the flight route as the weather evolves. The PDT approach is the development of the Integrated Turbulence Forecast Algorithm (ITFA), an infrastructure for automatically and continuously receiving observational and forecast weather data, as well as remote sensing and in-situ data, and then diagnosing this data to produce turbulence forecasts.

In addition to the above efforts, AWRP is engaged in a separate wind shear project associated with mountain-induced turbulence at Juneau, Alaska. Techniques being developed there are intended to enhance aviation safety in the region of the Juneau Airport by providing real-time wind information from anemometers and wind profilers at strategic locations. This information is being provided to the FAA, the National Weather Service (NWS), commercial airlines, and general aviation users.

Results of the PDT research can be accessed via the ADDS web page:
<http://adds.awc-kc.noaa.gov/>

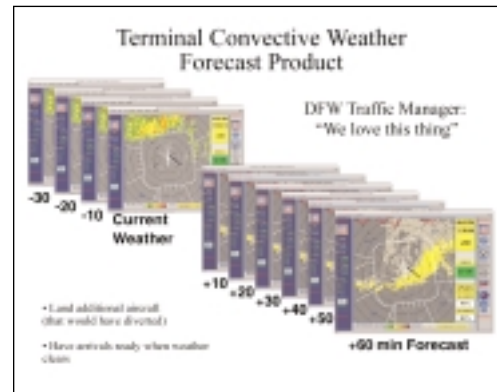
Benefits to the aviation community

- ◆ Smoother ride and decreased exposure to potential injury for passengers and crew
- ◆ Fewer hazardous encounters that are likely to cause damage to aircraft
- ◆ More timely strategic and tactical products
- ◆ More efficient use of national airspace

Convective Weather

Convective weather is the primary cause of national airspace delay and is also estimated to be the cause of more than half of the serious turbulence injuries. Existing operational forecast products are limited, and provide only 10-20 minute extrapolated positions of storms, with no accounting for storm evolution and only hourly updates of manually created convective SIGMETs.

Accurate, automated 1- to 2-hour forecasts of storms would result in the more efficient use of airspace and in reduced delays. Longer term, 2- to 6-hour national forecasts are need-



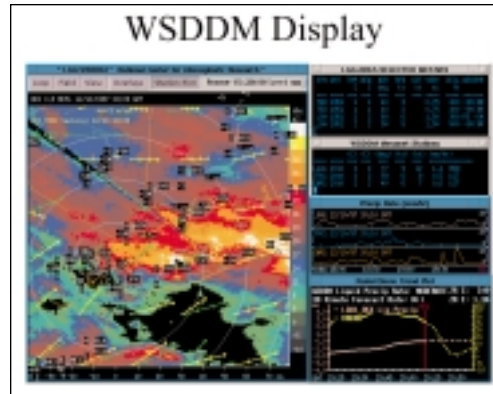
ed for flight planning and for traffic flow management decisions. The AWRP Convective Weather PDT has developed a 1-hour convective forecast product, using scale separation techniques that not only provide extrapolated positions of storms, but also the effects of growth and decay. This product has been demonstrated as part of the Terminal Convective Weather Demonstration at Dallas/Ft. Worth International Airport and provides the first automated 1-hour storm growth and decay forecast. Contact: webmaster@wx.ll.mit.edu for user ID and password.

A National Convective Weather Forecast product took the scale separation technology to airlines for en route utilization. En route advisories of convective weather are provided to airline dispatchers via the ADDS at: <http://adds.awc-kc.noaa.gov/>.

The majority of the data sources and techniques available for convective weather forecasting are most applicable over the continental US; FAA responsibilities extend over broad ocean areas and Hawaii. Beginning in FY01, AWRP is pursuing capabilities for convective weather products that are specifically intended for oceanic areas.

Winter Weather Research

The accumulation of ice and snow on aircraft prior to takeoff is a serious safety hazard. As little as 0.8mm of ice on a wing surface can increase drag and reduce lift by 25 percent. This type of buildup has been the cause, or a factor, in 10 commercial aircraft takeoff accidents between 1978 and 1997. In response



to this threat to aviation, the AWRP funded research that resulted in the development of the Weather Support to Deicing Decision-Making (WSDDM) System. WSDDM research has already resulted in enhanced operational safety and the technology has been transferred to industry for operational implementation.

PDT research has resulted in a stand-alone, integrated display system that uses all the following as principal sources of data: regional area Doppler radars; surface weather stations; and snow gauges located on and near the airport to determine precipitation type, temperature, wind speed and direction, and the amount of water in the snow. The WSDDM system integrates these parameters and provides critical deicing guidance, such as precipitation type, temperature and wind conditions, liquid snowfall equivalent, and a 30-minute forecast of precipitation intensity and movement so that near real-time aircraft deicing decisions can be made. These decisions center on when to de-ice, how often to de-ice, and the best type of deicing fluid to apply.

Benefits to the aviation community:

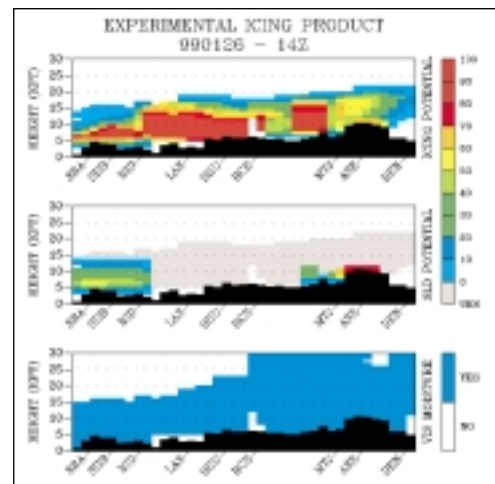
- ◆ Weather information important to safety is provided to decision makers such as pilots, air traffic controllers, ground service personnel, dispatchers, and airport managers
- ◆ Accurate and timely forecasts improve efficiency of deicing operations, reducing ground delays
- ◆ More efficient use of deicing fluid for a cleaner environment results in less run-off waste and savings in clean-up operations
- ◆ More efficient runway plowing operations reduce arrival and departure delays

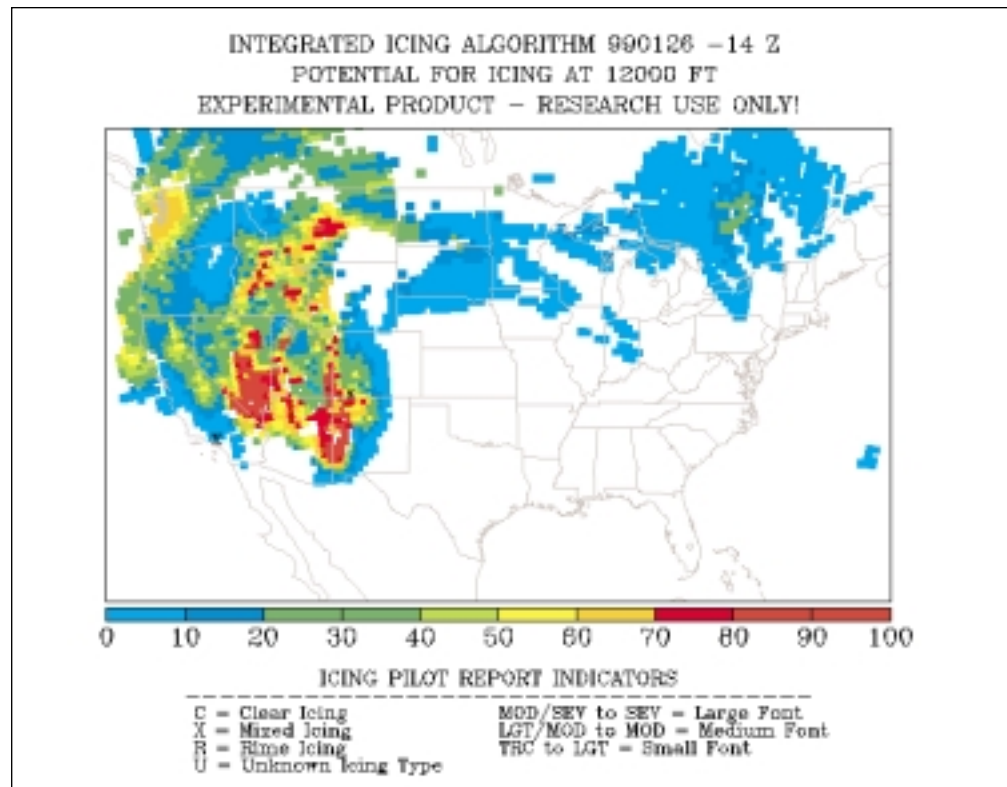
WSDDM research determined that the accurate measurement of liquid equivalent snowfall rate by snowgauges is one of the most important factors in determining holdover times of deicing fluids (time until a fluid fails to protect against ice build-up). Reported visibility during five of the last ten accidents mentioned above was light to moderate, although snowgauges at the airports indicated high liquid equivalent precipitation rates. Previously, airlines relied on pilot and National Weather Service estimates of snow intensity, both of which are based on prevailing visibility, not liquid equivalent. However, WSDDM research showed that large dry snowflakes, which reduce visibility the most, are less of a threat than small, wet flakes. This important finding increased awareness that visibility alone can be misleading for deicing aircraft decisions. An early benefit of WSDDM research was that USAirways, Delta, and United Airlines incorporated this finding into their winter training manuals for pilots.

In-Flight Icing

In-flight icing has been a factor in several fatal aircraft accidents and causes significant disruption to domestic flight operations. The goal of the In-Flight Icing PDT is to produce accurate hourly forecasts of icing conditions on high resolution grids. Technology developed by this PDT enabled the Aviation Weather Center (AWC) in Kansas City to issue the first ever forecast of freezing drizzle aloft.

Currently their Integrated Icing Diagnosis Algorithm (IIDA) is under testing and evalu-





ation by AWC forecasters in producing icing SIGMETs, AIRMETs, and area forecasts. It is expected to be released by the FAA for full operational use in the NAS in FY01. IIDA is available on ADDS webpage <http://adds.awc-kc.noaa.gov/>.

Efforts are also currently directed toward the development of an Integrated Icing Forecast Algorithm (IIFA), which will combine up to 56 interest fields into one integrated product.

Benefits to the aviation community:

- ◆ More accurate and timely information for flight planning and icing avoidance
- ◆ Detailed routing by flight dispatchers, through the use of higher-resolution IIDA output
- ◆ Remote sensor research to lead to ground-based terminal area or airborne ice detection systems

1.7 NASA Aircraft Icing Research for In-Flight Icing

The Aircraft Icing Research project supports the NASA AeroSpace Technology

Enterprise's "Global Civil Aviation" pillar. The research efforts address the aviation safety goal of reducing accident rates due to icing hazards and the affordability goal of reducing the time and cost of designing and certifying deicing systems. These goals are accomplished by developing methods and tools as a foundation to provide information and technology solutions for the aviation system. Major technology elements of the Aircraft Icing Research project include icing weather information, icing simulation, icing effects, icing operations, and icing education and training.

Shown in the accompanying picture is an icing phenomenon known as tailplane icing, wherein ice accreted on the horizontal stabilizer causes it to stall and results in uncontrolled pitch, a situation that has led to fatal general aviation aircraft accidents.

The joint FAA Technical Center and NASA Glenn program has identified the aerodynamic and handling characteristics of an aircraft in an ice-contaminated tailplane stall. Pilot training materials have been developed, based on the results of this investigation. The



training video, which is targeted to pilots of general aviation and commuter aircraft, describes the tailplane icing phenomenon, defines the expected handling characteristics of an aircraft in a tailplane stall, and explains the recovery maneuvers pilots can perform.

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1.8 “Food Grade” Anti-Icing Fluid

An anti-icing fluid developed at Ames Research Center promises to make flying safer without introducing dangerous chemicals into the environment. The patented new



fluid is so environmentally safe that it has been referred to as “food grade.” The new fluid contains propylene glycol, which is safe, instead of ingredients such as ethylene glycol and additives that can sicken or kill water life, animals, and human beings. In some respects, it works even better than current anti-icing fluids. The environmentally friendly fluid “grabs” onto an airplane’s surface more effectively than current fluids when the plane is at rest, providing a long-lasting barrier against ice buildup.

Worldwide, about one-half billion gallons of aircraft deicing fluid are used annually. Much of this could be replaced with the new fluid, thus reducing environmental costs, to government and industry and ultimately to taxpayers, for cleaning toxic anti-icing fluids from the environment.

The new anti-icing fluid has many more potential uses, such as on bridges, streets, runways, and railroad switches—and even around homes, for roofs and sidewalks. Because the fluid is nonconductive and neutral (neither an acid nor a base), roadways and bridges treated with the fluid will avoid corrosion of the rebar and other steel and concrete parts. Similarly, vehicles will avoid the body corrosion typically associated with the use of road salt. Power companies are interested in using a thicker, grease-like version of the fluid to protect substation electrical components and power cables from ice. Interest in commercial distribution of this product could potentially make it available next year.

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(Top, Left) The study of tailplane ice formation (inset) leads to better understanding of tailplane stall conditions and effective recovery procedures.

(Bottom, Left) Ice builds up on an aircraft wing, as the plane sits on the ground.

(Top, Right) Inventors show the new “food-grade” anti-icing fluid (held in beaker), which provides a long-lasting barrier to ice and does not harm the environment.



1.9 Runway Friction Index

Ice or snow on a runway was a factor in approximately 30 airplane accidents between 1983 and 1995. Inaccurate, incomplete, or confusing runway surface information was also a contributing factor in a number of cases in which airliners were dangerously slow in reaching liftoff speed because of the effect of snow, ice, or rain. A 5-year joint NASA, FAA, and Transport Canada research effort has been under way to focus on proving technology concepts for a better understanding of runway friction, improved tire designs, better chemical treatments for snow and ice, and new types of runway surfaces that minimize bad weather effects. Program support has been received from organizations in Scotland, Great Britain, Norway, Sweden, France, Germany, and Japan.

In a recent major accomplishment, the research team developed an international runway friction indexing method. To develop the index, researchers performed braking tests with ground-friction measuring vehicles and research aircraft on a variety of dry, wet, snowy, and icy runway conditions. The ongoing research focuses on relating the index to braking performance of different aircraft types and sizes. The index, which is anticipated to become an international standard for assessing runway conditions, will facilitate safe takeoff and landing decisions based on readings taken by a ground-friction measurement vehicle on the same runway. It will be a single, accurate, and easy-to-use tool to help both pilots and airport operators worldwide to quickly assess winter runway conditions. This index will help prevent accidents and reduce

unnecessary delays by providing airlines the necessary information to operate safely under adverse weather conditions.

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1.10 Pavement Testing Facility

The introduction of heavier aircraft with new gear configurations makes it essential that researchers gain a more accurate characterization of paving materials so they can increase design reliability and better estimate the effects of the larger aircraft. The next generation of large civil aircraft is expected to include models that will weigh up to 1.7 million pounds and have complex, multiple-wheel, multiple-truck landing gear systems. The first of this generation of aircraft, the Boeing B-777, which entered commercial service in June 1995, has two six-wheel landing gears and a gross weight of up to 535,000 pounds. The six-wheel gear loads applied to airport pavements by the B-777 are quite different from the loads of the current generation aircraft. Although current pavement design standards have worked well, they may not accommodate the dramatic changes associated with the next generation of airplanes currently being planned.

The FAA is developing new standard procedures capable of producing pavement thickness designs for all aircraft weights and landing gear configurations that might come into operation in the foreseeable future.



(Bottom, Left) The NASA 757 research airplane makes a test run on a snowy runway in Michigan.



The FAA's plan includes short-term research to meet the immediate needs arising from the introduction of new-generation aircraft, while pursuing long-term goals for improving the efficiency of airport pavement operations. The short-term research under way includes verification of design procedures based on current layered elastic analysis technology. The FAA's longer-term objective is to develop new design procedures. Essential to the development of these new design procedures is a comprehensive testing and validation program using full-scale pavement sections and dynamic simulated aircraft loading.

The creation of FAA's National Airport Pavement Test Facility was made possible through a Cooperative Research and Development Agreement between the FAA and the Boeing Company. The cost of the construction and the first year testing is \$21,000,000; the FAA and Boeing are sharing this cost. Subsequent costs will be the responsibility of the FAA.

- ◆ The test facility is capable of full-scale loading representing new generation, heavy civil transport aircraft. This load may comprise up to 75,000 pounds (34,020 kg) per wheel on two landing gears with six wheels per gear (a total of 12 wheels). It can handle single, dual tandem, and trident loading configurations, and will have the capability to change wheel spacing and gear spacing, with a maximum tire size at 56 inches (142 cm) overall diameter and 24 inches (61 cm) maximum width.
- ◆ The test pavement is 900 feet (270 m) long and 60 feet (18 m) wide. This width allows two gear configurations to be tested simultaneously. For example, a six-wheel B-777 gear can be tested in one lane and a four-wheel B-747 gear can be tested in the other lane. This direct comparison of two different gears is particularly important in finding a resolution for computing aircraft classification numbers for worldwide aircraft-airport compatibility.
- ◆ A total of nine test sections have been constructed of three subgrade materials (in a

range of 3 percent to 20 percent California Bearing Ration) for the first series of tests. There are three asphalt sections with an aggregate base, three asphalt sections with an asphalt-stabilized base, and three concrete sections with a cement-treated base. Test speeds, between 5 and 15 miles per hour, will represent worst-case pavement response. The facility will accommodate lateral wander patterns typical of airport runway operations. Pavement response sensors will measure strain, deflection, pressure, moisture, and temperature.

The preliminary operations plan calls for a comprehensive series of tests, designed to measure pavement response at different wheel and gear configurations. Tests will be performed to the point of pavement failure, with the expected failure rate of one test section per year. Pavement test-section reconstruction will be scheduled at 18-month intervals. The test vehicle can be programmed to skip, or "fly over," a failed section or sections.

Full-scale testing will provide the information urgently needed to investigate the performance of airport pavement that is subjected to the complex gear loads of the new generation of aircraft. The resulting technical data will help validate new design standards and assure compatibility between aircraft and airports throughout the world. The data will also provide an improved scientific basis for further development and refinement of the International Civil Aviation Organization's pavement loading standards for aircraft.

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1.11 Ground Arrestor Systems for Airports

Aircraft can and do overrun the ends of runways, sometimes with disastrous consequences. To minimize the hazards of overruns, the Federal Aviation Administration (FAA) requires a safety area 1000 feet in length beyond the end of the runway. Although this safety area is now an FAA



standard, many runways were constructed before its adoption. For those locations that do not have the space for a full safety area, soft ground arrestors provide an engineered solution to restore a margin of safety.

“Soft ground” means any material that will deform readily and reliably under the weight of an aircraft tire. As the tires crush the material, the drag forces decelerate the aircraft. The FAA and industry have developed mathematical models that aid in the design of these arrestor beds and predict aircraft stopping distances. Full-scale aircraft testing validated the model and set the stage for installation of these arrestor beds at major airports.

The arrestor beds have proved their worth. In May 1999, a SAAB 340 aircraft with 30 on board was brought to a safe stop after an overrun on runway 4R at JFK International Airport. The aircraft sustained only minor damage and only one minor ankle sprain was reported.

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1.12 Synthetic Vision

Limited visibility is the single most critical factor affecting both safety and capacity in worldwide aviation operations. Over the next five years, the Synthetic Vision Systems (SVS) project will develop technologies with practical applications to potentially eliminate low-visibility conditions as a factor in civil aircraft accidents.

The SVS Project Kickoff Meeting in November 1999 was held at the “terrain impacted” Asheville (North Carolina) airport. The meeting included successful flight evaluations of a state-of-the-art photo-realistic terrain database and NASA’s crew-centered Synthetic Vision Tactical Concept display. Over 60 varied approaches were performed during the 16 flights, demonstrating the potential of synthetic vision.

The meeting simultaneously launched eight unique SVS project cooperative agreements with industry and academia. NASA personnel provided a summary of the five-year, \$100 million SVS project plan. The cooperative agreement teams, representing over 25 diverse organizations including DOD, FAA, and airlines, provided an overview of their proposed projects.

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A terrain database for an area surrounding Asheville airport was used to create this photo-realistic display for use in a Synthetic Vision cockpit. A “flight” over this photo-realistic terrain can be performed on the CD version of this publication.

1.13 Airport Surface Safety Enhancement Technologies

The number of hazardous runway incursions has increased by more than 50 percent over the past four years. In many of these incidents, reduced visibility was a contributing factor. The NASA Aviation Safety Program's Synthetic Vision Systems Project is developing technologies to eliminate runway incursions in any visibility condition. These new technologies will provide controllers and pilots with supplemental guidance and situational awareness information that will significantly increase the safety and efficiency of aircraft movements on the surface.

A flight demonstration of a prototype system was conducted in August 1997 at the Hartsfield Atlanta International Airport in cooperation with the FAA. Both airborne and ground-based components were integrated, to provide the flight crew and controllers with additional information to enable safe, expedient surface operations. The prototype system consisted of several advanced technologies that made up an integrated communication, navigation, and surveillance (CNS) system. The flight demonstration validated the concept and enabled assessment of technology performance in an operational environment.

The demonstrated technologies included:

- ◆ Airborne Moving Map Display
- ◆ Head-Up Display
- ◆ Global Positioning System
- ◆ Ground-based surface surveillance systems
- ◆ Airport traffic identification



- ◆ Data links
- ◆ Air Traffic Control (ATC) interface

Benefits:

- ◆ Supplemental guidance cues and increased situational awareness
- ◆ Runway incursion avoidance
- ◆ Low-visibility surface navigation
- ◆ Reduced runway occupancy time and improved braking efficiency
- ◆ Reduced controller/pilot miscommunications
- ◆ Improved situational awareness in low visibility

NASA Langley researchers have simulated expanded system capabilities and plan to demonstrate these in-flight at Dallas-Ft. Worth airport in October of 2000, in conjunction with the FAA's Runway Incursion Reduction Program. These expanded capabilities include runway incursion advisories in the flight deck through onboard incursion detection algorithms and a data link to ground-generated alerts, a Local Area Augmentation System (LAAS) prototype, and an airport mapping database consistent with RTCA draft requirements.

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1.14 Fatigue Countermeasures Program

Responding to a congressional request, NASA created a program to examine whether “there is a safety problem of uncertain magnitude, due to transmeridian flying and a potential problem due to fatigue in association with various factors found in air transport operations.” The NASA Ames Fatigue/Jet Lag Program was created to collect systematic, scientific information on fatigue, sleep, circadian rhythms, and performance in flight operations.

Three program goals were established and continue to guide research efforts:

- ◆ To determine the extent of fatigue, sleep loss, and circadian disruption in flight operations
- ◆ To determine the impact of these factors on flight crew performance
- ◆ To develop and evaluate countermeasures to mitigate the adverse effects of these factors and maximize flight crew performance and alertness

Studies have been conducted with the support and collaboration of the FAA in a vari-

ety of aviation field environments and controlled laboratory settings, as well as in a full-mission flight simulator. In the early 1990's, the name of the program was changed to the Fatigue Countermeasures Program to provide a greater emphasis on the development and evaluation of countermeasures. Additional collaboration between NASA and the FAA's Civil Aeromedical Institute resulted in research to examine the impact of shiftwork on air traffic controllers' operational errors and incidents.

Recent studies include:

- ◆ An evaluation of the onboard bunk sleep of flight crews in augmented long-haul flights
- ◆ A 747-400 simulator study of the effectiveness of in-flight activity breaks for flight crews during long overnight flights
- ◆ A test of the feasibility of a video-based system for unobtrusively tracking and monitoring pilot fatigue

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747 pilots participating in the Cockpit Rest Field Study, performed in collaboration with the FAA.

1.15 Aviation Performance Measuring System (APMS)

The FAA and NASA have collaborated in developing advanced analysis tools for users of the U.S. Flight Operations Quality Assurance (FOQA) program. In cooperation with Alaska Airlines and United Airlines, the research team has developed the capabilities to convert large masses of flight-recorded data into meaningful quality assurance information. This provides timely operational awareness of safety and efficiency issues.

It is anticipated that APMS will play a central role in attaining the programmatic goals of the Aviation Safety Program and the FAA's Global Analysis and Information Network (GAIN) program. Under NASA's Aviation Safety Program, APMS will eventually be extended to service the needs of engineering and maintenance, and extended to commercial, commuter, cargo, and corporate air carriers as well as operations of large and small airports alike.

The FAA is conducting a related project to design data analysis methods for use in monitoring training program effectiveness. This project allows air carriers to compare crew performance in training simulators with crew performance in line operations. When safety threats are noted, air carriers can remediate the risk with future training opportunities. This project is in effect at Alaska Airlines and at Continental Airlines.

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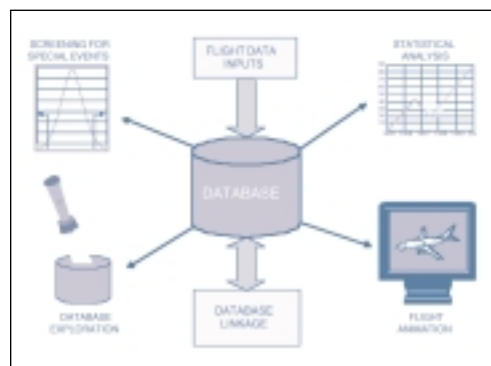
1.16 Aircraft Fire Safety

In its commitment to fire safety, the FAA operates the most extensive civil aircraft fire test facilities in the world. The centerpiece of this testing capability is a full-scale fire test facility, which is used to study fire scenarios under realistic conditions. Five other facilities are also devoted to conducting small-scale fire tests of interior materials, conducting fire tests of aircraft components and large-scale specimens, chemical analysis related to the toxicity of combustion products, putting out simulated engine fires, and examining the effects of altitude and air speed on fire behavior.

Through its fire safety program research and testing efforts, the FAA has set a number of industry fire containment standards, such as seat cushion fire-blocking layers and low heat and smoke release interior panels (sidewalls, stowage bins, ceilings, and partitions). The FAA's work also has led to heat-resistant evacuation slides and floor lighting, flight recorder fire endurance, Halon 1211 hand-held extinguishers, airline blanket ignition resistance, and guidelines for approving Halon replacement agents.

Engineers currently are working on numerous projects that focus on materials fire safety, fire management, and detection systems. For example, the agency is evaluating the fire performance of current thermal acoustical insulation, as well as the need for tougher fire test standards. Work will soon commence to develop test standards for approval of new cargo fire detectors that are being developed to reduce the high incidence of false alarms. In addition, cargo water spray tests are under way, to examine the effectiveness of this

(Left) An integrated suite of tools for routinely converting very large masses of flight-recorded data into information.



promising technology against various cargo fire threats, including exploding aerosol cans. Future research will address fire safety criteria in large passenger capacity, double-decked aircraft, which aircraft manufacturers are now designing.

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Airport Rescue and Firefighting Research Program

The FAA has a goal to increase aircraft passenger survivability during a post-crash fire. The FAA, through the Airport Improvement Program (AIP), provides financial assistance to FAA-certified airports for the purchase of heavy rescue and firefighting equipment. In addition, the FAA performs firefighting research in areas that will improve the effectiveness of or make better use of this same firefighting equipment.

The analysis of recent aircraft accidents involving external fuel fires has shown that although external fires are effectively extinguished, fires within the aircraft fuselage are difficult to control with existing equipment and procedures. Large amounts of smoke-laden toxic gases and high temperature levels in the passenger cabin can cause delays in evacuation and pose a severe safety hazard to fleeing passengers. Firefighters put themselves at great personal risk when attempting to extinguish any interior fire using hand-held attack lines.

The Aircraft Rescue and Fire Fighting (ARFF) R&D Program is currently expanding the capabilities of the National Airport Fire-Extinguishing Agent Performance Test Facility located at the FAA William J. Hughes Technical Center. The test facility consists of three parts:

- ◆ A full-scale, ground spill fire facility for testing new fire-extinguishing agents. That facility retains waste and spent fuel without endangering the environment.
- ◆ A full-scale aircraft facility with a planned second-level passenger configuration for

testing new equipment, firefighting tactics, and strategies.

- ◆ The FAA's advanced, high-performance rescue research vehicle (HPRV) with its 55-foot elevated boom and cabin skin penetration system.

Elevated Waterway and Cabin Skin Penetration Technology

The FAA conducted a research program to determine the effectiveness of using elevated waterway devices in conjunction with an aircraft cabin skin penetration system. To date, it has been easy to penetrate many different models of existing commercial aircraft designs by using a boom-mounted cabin skin penetration system. A demonstration program validated the effectiveness of injecting a fine mist spray into the burning interior of a Boeing Model 707 aircraft. During the demonstration, the intense fire was taken to severe flashover conditions and then brought back under control in two minutes with approximately five hundred gallons of injected water.





Fire suppression techniques are currently being validated to determine the most effective application of fire extinguishing agents to use for post-crash pool fires. The best application appears to be an attacking technique which deploys a boom at a low angle to sweep across a selected pool fire area, then raising it to a high-angle position for broader fire areas. This change can usually be accomplished without moving the rescue vehicle very far from its initial attack setup point.

Another benefit of the low-angle application is the increased visibility provided by getting the agent low and away from the vehicle. A typical roof turret agent application will result in a restricted view, with the agent running down the vehicles windshield.

The following photographs illustrate the reach and fire fighting tactics that are being explored in this program. To date, many different models of the existing commercial aircraft designs have been easily penetrated with the boom-mounted cabin skin penetration system.

1.17 Crashworthiness

As part of its effort to increase flight safety, NASA is conducting research to improve human survivability in airplane accidents. The first step is understanding the injury mechanisms and the limits of human survivability. To do this, researchers conducted a

detailed study of eleven transport aircraft accidents that had survivors.

The study revealed potential ways in which survivability could be improved. Physical changes were cited, such as better and more numerous exits, increasing the strength of restraint systems (the structure-floor-seat-occupant tie-down chain) to match human tolerance limits, improving retention of overhead luggage bins, and controlling the break-up of the aircraft fuselage. Other research findings point to improving fire suppression, decreasing the flammability and toxicity of the aircraft's interior components, increasing seat back height, and requiring restraints for all children.

General aviation aircraft and rotorcraft differ significantly from transport aircraft and therefore have different crash and survivability characteristics. The Crash Data Survey for rotorcraft and general aviation aircraft will be completed in early 2000, to guide the research for improving survivability for these classes of aircraft.

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NASA researchers crash-tested a Lear Fan 2100 at the Impact Dynamics Research Facility to evaluate improved crashworthiness design features that will increase human survivability and reduce injuries in the event of an accident.



Efficiency/Capacity

The current air transportation system in the United States is experiencing significant delays, decreased efficiency, and increased costs. This is especially true during adverse weather conditions. Over the next 20 years, the demand for air travel is expected to double, making these problems much more severe unless new capabil-

ities are developed and made operational. To assure that these predictions do not become reality, major new improvements to the air transportation system are required. NASA and the FAA are collaborating in efforts to ensure the efficiency, safety, and cost-effectiveness of the future National Airspace System.



Airplane lined up on the taxiway awaiting take-off. Photo by: Darren Anderson.

Goal: To safely enable major increases in the capacity and productivity of the National Airspace System (NAS) in all weather conditions, through the development of revolutionary operations systems and vehicle concepts.

NASA research will provide:

- ◆ Safe, clear-weather airport capacity in instrument-weather conditions
- ◆ Hardware and software decision support tools to enable the “free flight” concept in the NAS
- ◆ Critical technologies to enable scheduled civil tiltrotor service, to add capacity and reduce delays

FAA research will provide:

- ◆ Surveillance, navigation, and landing applications of Global Positioning System technology
- ◆ Enhanced aviation weather forecasting capabilities—knowing accurately when and where aviation weather hazards will occur
- ◆ Insight into the future roles of pilots and controllers as the NAS evolves toward free flight
- ◆ Redesign of the nation’s airspace and airport approaches/departures to fully utilize the advances of technology
- ◆ Automation tools to support collaborative decision making between air carriers and the FAA and to allow more flexible flight planning
- ◆ Exploration of new wake vortex detection and tracking technology

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2.1 FutureFlight Central

A new research facility dedicated to counter-acting potential air and runway traffic problems at commercial airports was opened at a dedication ceremony at NASA Ames Research Center December 13, 1999. Called FutureFlight Central, this unique, full mission, real-time simulator will be used to validate future airport surface and air traffic control tower technologies and airport procedural and physical modifications. By studying new tools and plans in simulation, FutureFlight Central will enable optimized, cost-effective solutions to airport surface capacity and safety problems into the 21st century.



Several key features combine to create a realistic operational environment. High-resolution graphics powered by a state-of-the-art image generation supercomputer provide a visual scene of unprecedented realism. The system is capable of smooth animation of up to 200 simultaneously moving models; it incorporates shadow effects, photographic quality texture mapping, and three-dimensional objects. The images are presented on twelve screens, joined seamlessly to form a full 360-degree view. FutureFlight Central is reconfigurable to replicate any airport using site-specific visual models, custom-designed traffic scenarios, simulated telephone and radio communications, and tower layout.

FutureFlight Central will make possible in-depth studies using human participants as air traffic controllers, flight data/clearance delivery personnel, traffic management coordinators, tower cab coordinators, super-

visors, ramp controllers, pseudo-pilots, and airport operators in a real-time, interactive, operational airport environment. These studies in benefit validation, pre-deployment site adaptation and human factors assessments will result in a reduction of cost and associated risks of new technologies.

As an airport planning tool, FutureFlight Central will be invaluable for evaluating airport expansion designs against current and future traffic loads. Ground procedures can be tested under nominal as well as adverse weather or emergency conditions to assure that they are ready for implementation. Benefit analyses will be possible before costly investment is made, through quantitatively assessing, in simulation, the impact of new configurations and technologies using realistic traffic levels.

According to Air Traffic Management Magazine, Nov/Dec 1998, "NASA's FutureFlight Central stands a clear chance to solve the most pressing capacity problems facing 21st century airports and is one of the most powerful simulators in the world."

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2.2 Advanced Taxiway Guidance System (ATGS)

The FAA has designed, installed, and evaluated a prototype Advanced Taxiway Guidance System (ATGS) at its FAA William J. Hughes Technical Center. This system automatically guides aircraft to and from the runway and ramp areas during nighttime and/or low visibility weather conditions. ATGS incorporates state-of-the-art technologies that uniquely identify aircraft and automatically control taxiway lights without input from any radar devices. The main benefits of this system are as follows:

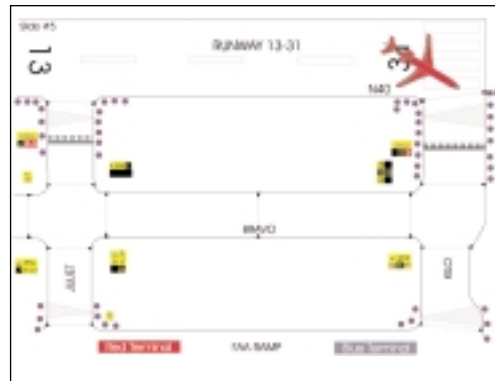
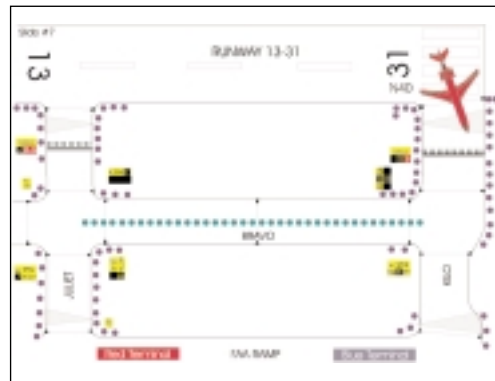
- ◆ The system will automatically illuminate a specific taxiway route for each arrival and departure thus lessening the chance of pilot route deviations and runway incursions.

- ◆ The system will potentially allow for more economical operation of taxiway lighting during low traffic periods, since the appropriate taxiway routes will be illuminated only when needed to guide arriving or departing aircraft to their destination on the airport surface.

The prototype system was installed and evaluated on a runway/taxiway/ramp complex at the Atlantic City International Airport (ACY). The results of this evaluation indicate that the subject pilots thought that it was an excellent system/concept. More specifically, they stated that implementation of an ATGS would help to improve airport/aircraft safety by reducing the chances of incorrect turns and runway incursions, particularly during night and/or low-visibility operations.

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Configuration of the ATGS Taxiway test bed at the Atlantic City International Airport.

2.3 Aircraft Vortex Spacing System

The Aircraft Vortex Spacing System (AVOSS) integrates output from systems that provide current and predicted weather conditions, models of wake vortex transport and decay in these conditions, and real-time feedback from wake behavior sensors to produce weather-dependent, dynamic wake vortex spacing criteria for arriving aircraft.

During 1999, AVOSS system enhancements were completed for an FY 2000 real-time engineering-model demonstration of the Terminal Area Productivity Project at Dallas-Ft. Worth Airport. Here, AVOSS use during instrument approach conditions could boost arrival capacity by six to nine percent. Gains of over 10 percent may be achieved at other airports.

Although AVOSS technology currently focuses on enhancing airport traffic capacity for arrivals on a single runway, it could be applied to aircraft departures and parallel runway operations.

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2.4 Airborne Information for Lateral Spacing

Airborne Information for Lateral Spacing (AILS) is an airborne-based concept for landing under instrument conditions at airports with closely-spaced parallel runways. An airline's ability to maintain schedules is severely impacted when one or more airports are forced to curtail independent parallel approaches because of inclement weather.

The AILS system would safely maintain high airport acceptance rates under conditions not possible with current systems and procedures. AILS provides an independent instrument approach capability applicable to parallel runways with centerline spacing within the range for most domestic hub airports.

A flight demonstration of AILS was held in mid-1999 by NASA and Honeywell, Inc. at Minneapolis-St. Paul International Airport. This successful event allowed industry, airline, and government representatives to witness continued safe separation between aircraft, even under simulated flight conflicts. This was a key achievement on the path to a flight-certifiable system to be developed by industry.

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(Left) An AVOSS concept demonstration was successfully performed at the Dallas-Fort Worth International Airport in July 2000, where an initial version of AVOSS has been in operation since 1997.



The AILS concept alerts the crew of flight path deviations and potential collision threats. The Primary Flight Display (inset) and Navigation Display depict a message requiring the crew to fly the procedural emergency escape maneuver to ensure continued safe separation between the aircraft.

2.5 Global Positioning System

Wide Area Augmentation System (WAAS)



The WAAS is a geographically broad augmentation to the basic Global Positioning System (GPS) service designed to improve the accuracy, integrity, and availability of the basic GPS service. Initial benefits will be provided by Phase I WAAS.

When Phase I is operational, WAAS will provide pilots with an en route through precision approach capability. En route through non-precision approaches will be available throughout the entire service area with an availability of 99.9 percent. Precision approach coverage will be provided in central regions of the continental United States (CONUS), serving approximately 50 percent of CONUS airports. Availability for precision approach is designed to be 95 percent.

Although WAAS offers the potential to replace Very-High-Frequency Omni-Directional Radar (VOR), Distance Measuring Equipment (DME), and Non-Directional Beacons (NDB) in the U.S., further enhancements are needed to the Phase I WAAS before this is possible.

The commissioning of Phase I WAAS for public use will take place in the Fall of 2000; however, in mid-1999 a signal capable of supporting non-safety applications, such as an aid to Visual Flight Rule (VFR) flight, became available.

Local Area Augmentation System (LAAS)

The other augmentation to the basic GPS service is the Local Area Augmentation System (LAAS). Similar to the WAAS concept, which incorporates the use of geosta-

tionary communication satellites to broadcast a correction message, the LAAS will broadcast its correction message via very high frequency (VHF) radio datalink from a ground-based transmitter.

The LAAS will meet the more stringent Category II/III requirements that exist at selected locations throughout the U.S. LAAS is intended to complement and function together with the WAAS, to supply users of the U.S. National Airspace System (NAS) with seamless, satellite-based navigation for all phases of flight. In practical terms, this means that at locations where the WAAS is unable to meet existing navigation and landing requirements (such as availability), the LAAS will be used to fulfill those requirements. In addition, beyond Category III, the LAAS will provide the user with a navigation signal that can be used as an all-weather surface navigation capability. This will enable the potential use of LAAS as a component of a surface navigation system and an input to surface surveillance/traffic management systems. It is fully expected that the end-state configuration will pinpoint the aircraft's position to within one meter or less, and do so at a significant improvement in service flexibility and user operating costs.

Additionally, both the WAAS and LAAS have the backing of aviation's main user groups—the Air Transport Association (ATA) representing air carriers, and the Aircraft Owner's and Pilot's Association (AOPA) representing general aviation. These groups confirmed their support in an April 1998 press release which stated "the joint recommendations ask the Federal Aviation Administration to proceed with both wide-area and local-area augmentation systems for



Global Positioning System (GPS) satellite navigation.” Encouraged by these recommendations and the benefits that can be provided by WAAS and LAAS, the FAA remains strongly committed to these programs.

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2.6 Data Link

Controller Pilot Data Link Communications (CPDLC) will supplement many of today’s routine voice transmissions with digital data communication messages. CPDLC opens the way for transmitting a wealth of new information that will significantly alter the way air traffic is managed from predeparture through landing, improving flight safety and efficiency, and potentially saving the aviation industry billions of dollars.

Over the past several years, the FAA has evolved a comprehensive plan for building an air traffic management (ATM) system. This system will support future global flight planning, aircraft operation, and ATC services through the introduction of advanced communications, navigation, and surveillance technologies. A key feature of the future ATM will be the use of CPDLC data communications as a primary means for exchanging aeronautical information and delivering ATC services.

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2.7 Free Flight Phase I

The FAA’s Free Flight Phase I (FFP1) program will introduce modernization into the national airspace incrementally—taking a building block approach to fielding new systems to provide benefits to users as soon as possible. The goal of FFP1 is to move toward free flight operations, by limited deployment of systems based on current R&D prototypes that provide core free flight capabilities. The result will be near-term realization of air traffic management capabilities that have early benefits for service providers and National Airspace System users. FFP1 products will be operational at selected facilities by the close of 2002.

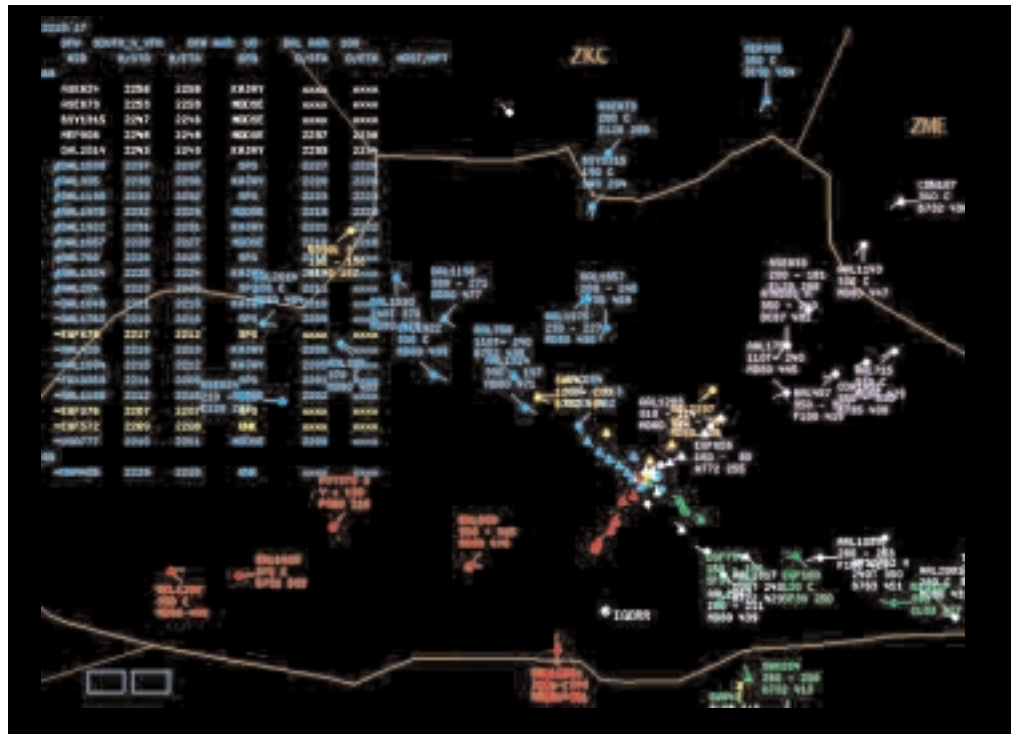
NASA has conducted the enabling research for three of the five tools under the FAA’s Free Flight Phase 1 program.

<http://ffp1.faa.gov>

Traffic Management Advisor-Single Center

Traffic Management Advisor-Single Center (TMA-SC) is based on the research and prototypes of NASA. As deployed under FFP1, TMA-SC provides en route air traffic controllers and traffic management specialists with computer automation and graphical tools to coordinate arrival traffic for selected airports. The TMA-SC reduces airspace system delays by enhancing arrival throughput and efficiency of air traffic operations in the extended terminal airspace surrounding major airports—without decreasing safety. Efficiency and throughput increases translate into fuel savings for airlines and reduced passenger delays for the public.

TMA is operational at the Fort Worth and Minneapolis high altitude centers and will be deployed to five additional ARTCCs. The TMA at Fort Worth Center improves the traffic flow into TRACON and communication between TRACON and center. It has resulted in a 5 percent increase in acceptance rates. Remote TMA displays (with no processing or TMA interactive capability) can be deployed to TRACONs and adapted airport towers associated with each TMA site.



TMA and the passive Final Approach Spacing Tool form part of the NASA developed Center-TRACON Automation System.

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USER Request Evaluation Tool

The User Request Evaluation Tool (URET) is a strategic planning automation tool for the Air Route Traffic Control Radar Assistant, or D-Side Controller. URET assists the Sector Team in evaluating alternative aircraft routings and altitudes to determine whether they are conflict free. It also automatically notifies the affected controller when a conflict between aircraft or Special Use Airspace is predicted to occur within the next 20 or 40 minutes respectively. URET is presently in daily use center wide at both Indianapolis and Memphis ARTCCs.

Through URET's strategic notification and trial planning capabilities, a controller has more lead time to assess traffic situations and identify appropriate conflict-free resolutions. The additional lead time allows a controller to properly assess and confidently approve more pilot-requested flight plan amendments, knowing they will be conflict-free. URET will be deployed incrementally to seven ARTCCs in order to incorporate functional improvements and user feedback.

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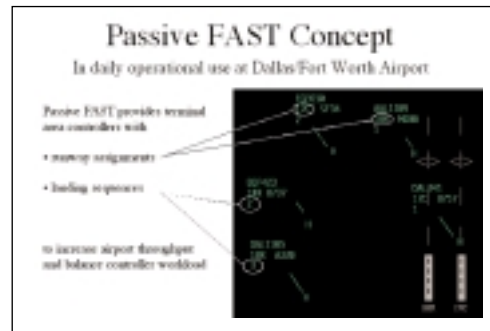
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(Top) Use of Traffic Management Advisor software improves air traffic flow into TRACON.

(Bottom, Right) URET prototype currently installed at Indianapolis and Memphis centers.

Passive Final Approach Spacing Tool (pFAST)



Both passive Final Approach Spacing Tool (pFAST) and the Traffic Management Advisor (TMA) form the NASA-developed Center-TRACON Automation System. As deployed under Free Flight Phase 1, pFAST affects traffic flow and planning of aircraft operating in terminal air space; it provides TRACON controllers with aircraft runway preferences and sequence numbers.

The CTAS suite of tools increases arrival acceptance and efficiency of air traffic operations in the extended terminal airspace surrounding major airports without decreasing safety. pFAST does this by providing automation aids to assist controllers in optimizing the flow of traffic to adapted airports within the Air Route Traffic Control Center/TRACON; and, the use of available runways and surrounding airspace. Early indications from Dallas-Ft. Worth show that an extra 2 aircraft per rush (30 minute period of heavy traffic – 9 rushes daily) are able to land at the airport.

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(Bottom, Left) Controllers at Dallas/Fort Worth TRACON using pFAST to sequence arrival traffic.

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Surface Movement Advisor

Surface Movement Advisor Free Flight Phase 1 (SMA FFP1) facilitates the sharing of aircraft arrival information with airlines to augment decision-making regarding the surface movement of aircraft.

- ◆ Although the SMA concept is based on NASA research, the SMA FFP1 implementation is significantly different from the NASA prototype currently in use at Hartsfield Atlanta International Airport.
- ◆ Automated radar terminal system data is available to airlines so they will have predicted knowledge of aircraft arrival information that can be used to compute an aircraft's estimated touchdown time.
- ◆ SMA FFP1 information has been available at Philadelphia International and Detroit Metropolitan Airports since mid-December 1998 and at Chicago O'Hare, Dallas-Fort Worth, Newark, and Teterboro Airports since December 1999.
- ◆ SMA FFP1 enhances airline gate and ramp operations that result in more efficient movement of aircraft while they are on the ground

Early feedback from Northwest Airlines at Detroit is very positive. As a result of the enhanced situational awareness Northwest estimates that they will be able to avoid three to five costly flight diversions weekly during inclement weather.

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Collaborative Decision Making

Collaborative Decision Making (CDM) provides Airline Operations Centers and the FAA with real-time access to National Airspace System status information including weather, equipment and delays. This collaboration helps manage the airspace more efficiently.

The near term objectives for CDM are to:

- ◆ Validate the estimated reduction in delays resulting from increased information sharing across all airports in the U.S.
- ◆ Evaluate and institutionalize new procedures that improve flight routing under severe weather avoidance conditions and congestion
- ◆ Continue the expansion of joint FAA/industry information exchange mechanisms
- ◆ Release FAA real time sensor and resource status data to improve efficiency

Three components comprise the CDM program:

- ◆ Ground Delay Program Enhancements
- ◆ Initial Collaborative Routing
- ◆ NAS Status Information

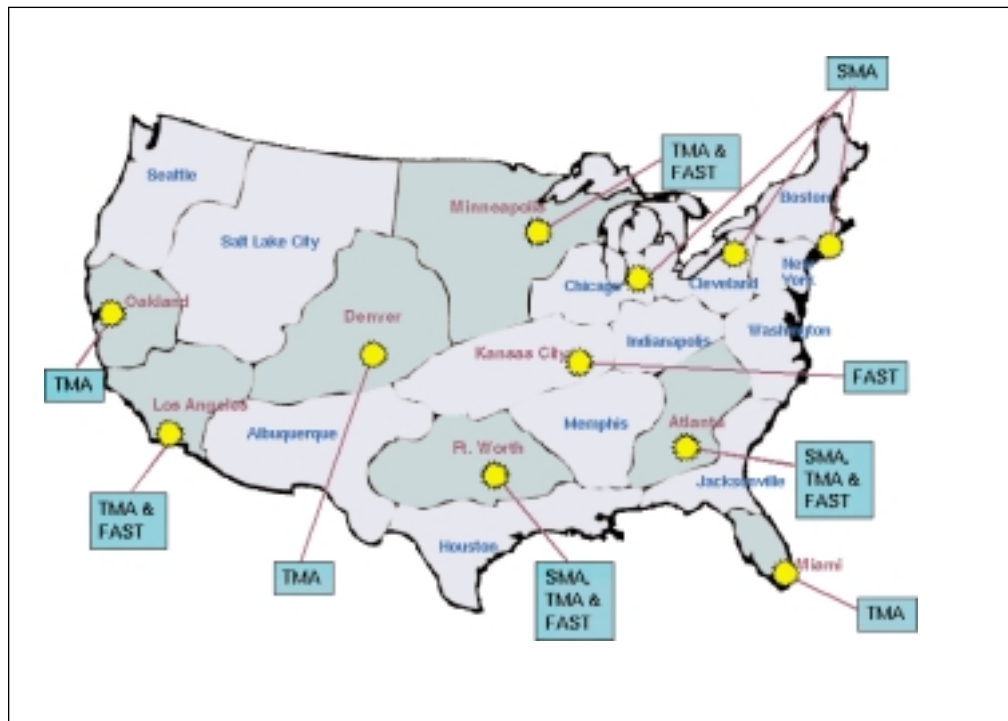
The FAA's Free Flight Phase 1 Program Office is addressing the goals and objectives of CDM by continuing to engage the user community to achieve the consensus capabilities articulated by RTCA. Specifically, FFP1 continues to interact with the operational community to ensure that all capabilities that are deployed address real operational concerns. The Ground Delay Program Enhancements component of CDM has allowed airlines to avoid over 9.1 million minutes* of costly delay since it became available to all airports on September 8, 1999. (*as of June 30, 2000)

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The FAA is deploying NASA-developed systems as part of the Free Flight Phase I.

2.8 NASA: Beyond Free Flight Phase I Tools

While FFP1 lays the foundation for addressing many of the efficiency problems of the NAS, it does not address all of the user needs that will exist in the future. Many of these needs will be generated by the growth of air traffic in the U.S. and worldwide. According to the FAA, air traffic in the U.S. will grow steadily over the next decade. Activity at towered airports in the U.S. in 1998 exceeded 65 million operations. By 2010, the FAA estimates, this number will exceed 81 million.

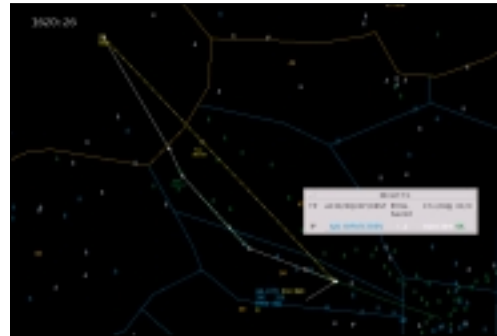
NASA is working hand in hand with FAA and its federally funded Research and Development Center (MITRE's Center for Advanced Aviation System Development) to address future ATM needs of the NAS, including the development of new tools for greater efficiency gains. Air traffic management research and development continues to be a critical element in the full modernization of the NAS as we move beyond FFP1. The following tools are now in development.

Collaborative Arrival Planning (CAP)

CAP is focused on improving air carrier hub operations. Today, arriving aircraft are handled on a first-come, first-served basis, without regard to air carrier business concerns. Inevitably, air carrier arrival timing miscues, caused by aircraft maintenance, airport congestion, or severe weather, lead to air carrier inefficiencies such as missed flight connections, inefficient hub operations, and aircraft diversions. Providing air carriers with improved predictive information on their arriving flights and the ability to alter arrival times to prevent timing miscues are the principal objectives of CAP. The potential annual savings: \$75M.

Direct-To Tool:

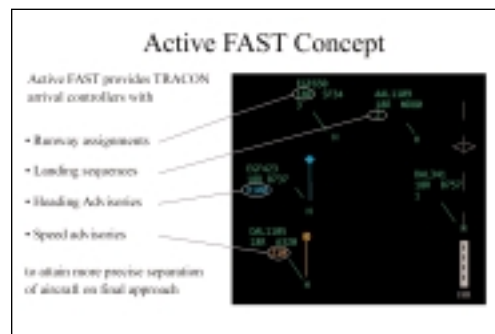
Researchers at NASA have created a new automation tool for enroute air traffic controllers, called the Direct-To Tool. The tool can be used by controllers to optimize routing of departures and en route traffic, to minimize flight time and fuel consumption, and avoid conflicts.



The tool has been running since January with live radar data received at NASA from the Fort Worth Air Route Traffic Control Center. Controllers, FAA officials and airline managers, who have seen the Tool in operation at the NASA laboratory, have expressed enthusiastic interest in it.

By counting up the potential time savings of all direct-to re-routings identified by the Direct-To Tool over a period of time since the tool went on-line at the NASA laboratory in January, an estimate of its time savings potential has been obtained. Field tests at Fort Worth Center began in October 1999. If installed at all sectors in the Fort Worth Center, the tool has the potential to save in excess of 500,000 in-flight minutes per year. For comparison, these benefits could exceed—and are in addition to—the combined delay reductions provided by the CTAS tools TMA and FAST, which are currently in use at the DFW airport. A provisional patent application for this tool has been filed.

Active Final Approach Spacing Tool (aFAST)



Active FAST is a decision support tool designed to achieve more accurate aircraft separation on final approach. As a follow-on to the

(Bottom, Right) Active FAST Concept.

previously developed and implemented Passive FAST, aFAST will provide active advisories, namely heading and speed. In addition, aFAST will generate sequencing and scheduling information. An additional 10% capacity improvement is expected from pFAST.

Surface Movement System (SMS)

Builds from SMA to achieve additional reductions in surface delays and optimize surface movement, and enhance airport situational awareness of aircraft movements.

Expedite Departure Path (EDP)

Provides speed, heading, and climb advisories providing unrestricted climb profiles, reduced near-airport fuel emissions, and increased airport capacity.

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2.9 FAA: Beyond Free Flight Phase 1

Air traffic management research and development continues to be a critical element of full modernization of the NAS as we move beyond FFP1. In both the near- and the long-term, the FAA is working to expand FFP1 capabilities geographically and to increase functionality. Building on the framework of FFP1, the FAA also seeks to increase the level of integration among various FFP1 components to achieve greater efficiencies, redesign the airspace, and add further procedural enhancements. Among current research and development efforts under way are:



(Bottom, Left) FAA Air Traffic Control Facility

Flight Management System/Area Navigation Routing (FMS/RNAV)

FMS/RNAV will provide shorter paths to the runway to minimize flight time variations caused by vectoring and airport delays. This program utilizes advanced equipment in aircraft cockpits. (The figure below illustrates the route definition tool under development.)

Flow Management Restriction Reduction

Designed to reduce the level of restrictions in place in the NAS at any time. Analyses are being performed to determine which restrictions can be safely eliminated.

Enhanced En Route Conflict Resolution Capabilities

To assist controllers in constructing flight plans more quickly, especially in situations of heavy workload or complex traffic patterns. Work is under way to develop and evaluate this logic, building on existing URET capability.

Collaborative Decision Making (CDM)

Continued research to better provide common information that enables traffic flow managers and airspace users to make more informed decisions. Multiple activities are under way to develop tools that will be needed beyond FFP1.

Operational Concept Development

Provides a structural set of relational responsibilities and actions for controllers, traffic flow managers, pilots, and users' operations centers, for achieving a desired operational enhancement. The concept is used to define required procedures, information flows, communication bandwidths, and decision support systems required for the successful evolution of the NAS.

Traffic Flow Management Impact Assessment

Will assist traffic flow managers and airspace users in understanding the potential results of proposed TFM actions on a NAS-wide basis. A fast-time simulation capability is under evaluation to identify requirements and to develop a prototype capability.

Collaborative Routing Coordination Tools (CRCT)

Provides information for traffic flow managers and airspace users so they can recognize, analyze, and resolve traffic flow problem situations.

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2.10 Civil Tiltrotor Aircraft

Because a tiltrotor airliner can take off and land vertically, there are two major benefits of a CTR:

- ◆ A tiltrotor aircraft can add additional capacity to an airport and reduce delays.
- ◆ Significant reduction of door-to-door trip times for passengers, by circumventing ground and air congestion

Expansion of the capacity and reduction of the runway congestion at the busiest airports by permitting some short-haul traffic (trips of less than 500 miles) to shift to tiltrotors, freeing runway space for larger aircraft.

NASA's Civil Tiltrotor research is developing the most critical vehicle technologies for a civil tiltrotor:

- ◆ Efficient, low-noise propotor
- ◆ Integrated cockpit for minimum pilot workload during low-noise approaches and departures near congested terminal areas
- ◆ Safe and cost-effective contingency power capability for emergencies when one engine is inoperative.

Regarding a tiltrotor airliner using simultaneous non-interfering approaches:

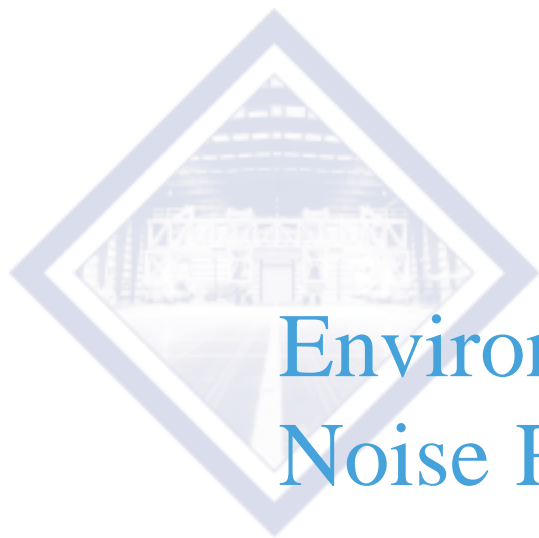
- ◆ A January 1999 FAA study indicates that one tiltrotor vertiport at Newark International Airport can provide 50 percent as much delay reduction as a new runway.
- ◆ The difference in up-front infrastructure costs (\$3B for the average new runway versus \$17M for a vertiport added to the airport) makes the tiltrotor an attractive prospect.

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This 40-passenger tiltrotor airliner concept would not need a runway, because it takes off vertically.



Environment: Aircraft Noise Reduction

The 1995 White House National Science and Technology Council report, *Goals for a National Partnership in Aeronautics Research and Technology*, states that “Environmental issues are likely to impose the fundamental limitation on air transportation growth in the 21st century.”

Noise impact of aircraft operations is already constraining the air transportation system through curfews, noise budgets, and slot restrictions. Noise issues are also inhibiting expansion or construction of new facilities. Increasing stringency in aircraft noise standards has mandated phase-out of stage 2 airplanes by the year 2000, and the number of airports affected by local noise restrictions has grown from 119 airports in 1980 to 595 in 2000 worldwide.

The EPA has established that a Day-Night Average Level of 55 decibels is “requisite to protect the public health and welfare with an adequate margin of safety.” The FAA and NASA vision for a noise-free constraint-free air transportation system has a goal of not exposing the population beyond airport

boundaries to any greater noise level. This will benefit the public in terms of increased quality of life and readily available and affordable air travel, and our aviation industry will enjoy continued global leadership.

The essential objective is to “Reduce the perceived noise levels of future aircraft by a factor of two (10 decibels) relative to 1997 subsonic aircraft within 10 years and by a factor of four (20 decibels) within 25 years.” This will be achieved, in cooperation with U.S. industry, via systematic development and validation of noise reduction technology in three areas: engine system, aircraft system, and operational procedures. The previous strong coordination among government, industry and academia will continue to effectively transition noise reduction technology to the U.S. industry.

As we progress toward this goal, the FAA’s responsibility will be to develop and implement near-term programs to control today’s aircraft noise. An important aspect of that job is the development of computer models that give insight into the system-wide conse-

quences of alternative courses of action. Implementation of those models will allow both local and national authorities to make effective decisions to protect the public health and welfare as technology advances toward the vision of communities free from aircraft noise.

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3.1 FAA Integrated Noise Model

The FAA has developed the Integrated Noise Model (INM) for evaluating aircraft noise impact in the vicinity of airports. The current INM series has been ordered and shipped to over 650 organizations worldwide, making it the most popular model of its kind. The distribution package for the model includes the INM software (on 3.5-inch diskettes), a user's guide, and a technical manual.

demand levels, revised airspace structure or modifications to operational procedures. The INM has been the FAA's standard tool since 1978 for determining the predicted noise impact in the vicinity of airports. Statutory requirements for INM use are defined in FAA Order 1050.D, Policies and Procedures for Considering Environmental Impacts; Order 5050.4A, Airport Environmental Handbook; and Federal Aviation Regulations (FAR) Part 150, Airport Noise Compatibility Planning.

The INM model produces noise exposure contours that are used for land use compatibility maps, and it includes built-in tools for comparing contours and utilities that facilitate easy export to commercial Geographic Information Systems. INM also calculates predicted noise at specific locations such as hospitals, schools, or other sensitive areas. The model supports 13 predefined noise metrics, and the user may also create special metric types.

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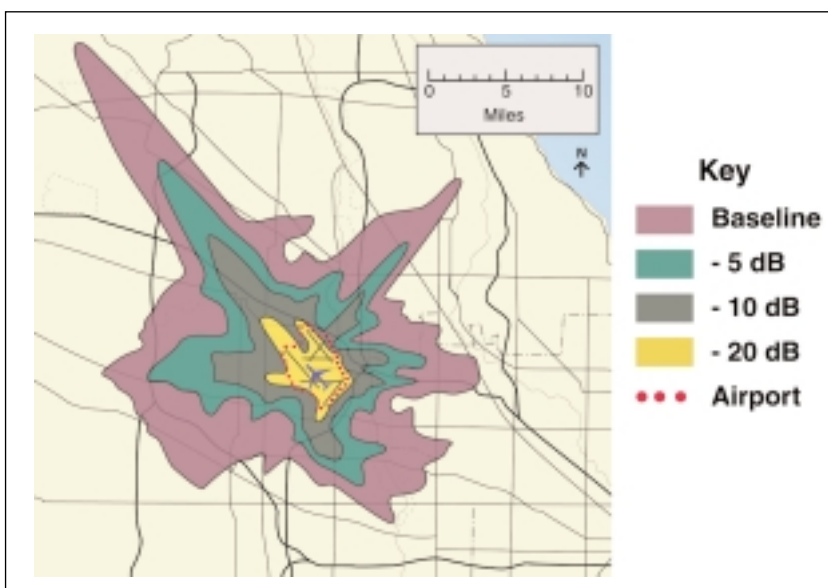
3.2 Community Noise Impact Model

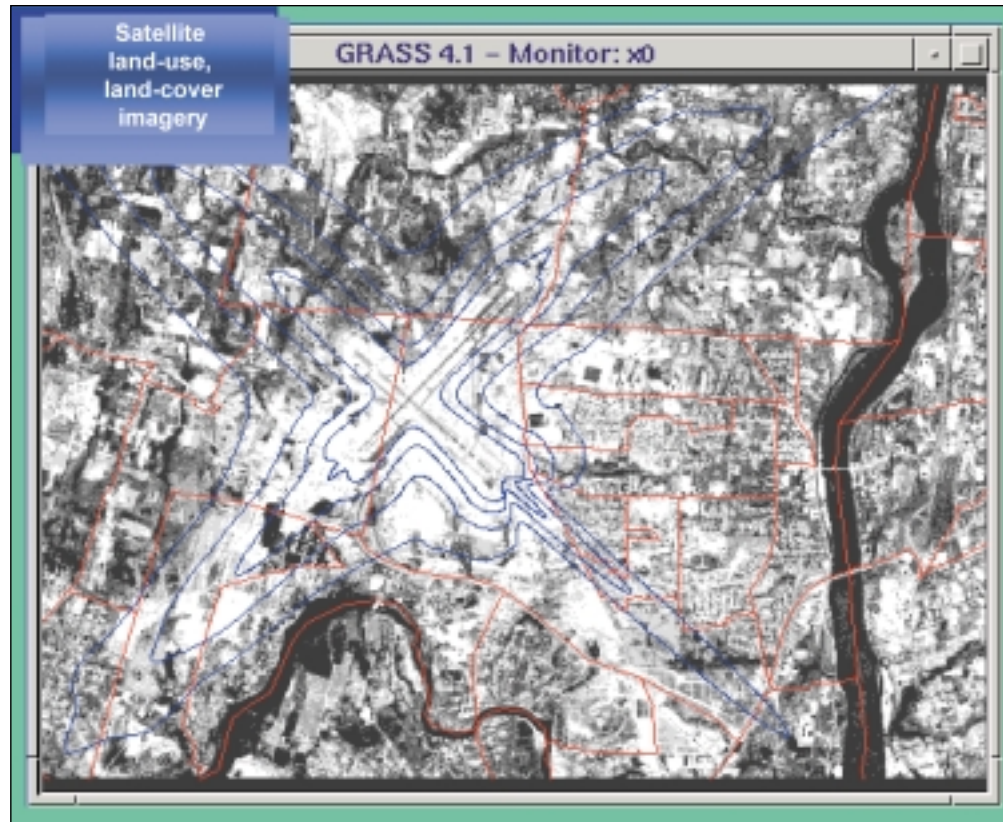
Accurately predicting the impact of noise on a community is critical to developing strategies for mitigating noise impact and for determining the need for and benefits of technology to reduce noise. In FY 1999, researchers at NASA developed a community noise impact model called the Aircraft Noise Impact Model (ACNIM). The model is a computer program that incorporates airport noise prediction, census data, and satellite imagery into a user-friendly geographical information system. It also incorporates the FAA's Integrated Noise Model, which is the standard airport noise prediction model used around the world.

The resulting impact assessment model was greatly improved over earlier efforts. First, the census data and satellite imagery included in the model provided more accurate esti-

*(Below) Benefits of
NASA technology
demonstrated by INM.*

INM has many analytical uses, such as assessing changes in noise impact resulting from new runway configurations, new traffic





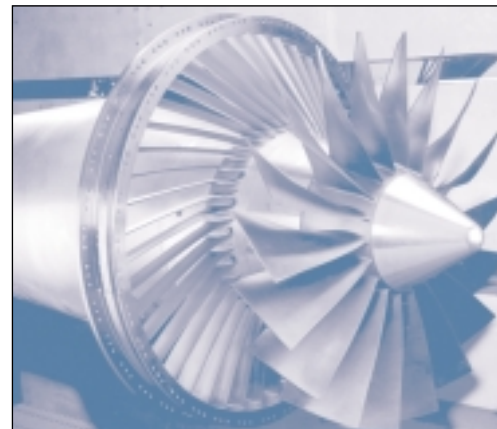
mates of population density and location. Second, the ability to predict community impact was improved by including more accurate models of noise-induced sleep disturbance and response to the noise of future airplanes, which potentially could sound different from today's airplanes. Third, the model can determine optimized airplane ground tracks and trajectories that would minimize the impact of noise in nearby communities.

Results of studies with the developed models indicate that, if combined with advanced operational procedures, improved high-lift systems have potential to reduce community noise impact by the equivalent of a 2-4 dB reduction in source noise. Future plans include incorporating the developed operational procedures into an integrated air traffic management system that is being proposed in potential new initiatives.

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3.3 Fan Noise Reduction

An engine fan noise reduction of 3 decibels was achieved with an innovative, low-noise stator design. This design has the potential to effectively eliminate fan tone noise as a significant contributor to community noise. This is a tremendous achievement in that it accomplishes what fan tone noise research over the past 30 years had not yet produced. With the new stator, engine designers can direct more attention to reducing fan broadband noise.



(Top) Graphic from the new community noise impact assessment model, showing increased accuracy for airport noise contours and census tracts superimposed on the satellite image.

(Bottom, Right) Swept and Leaned Stator Model

The 3-decibel fan noise reduction was met through a combination of a low-noise fan design and cycle changes, which were validated in high-fidelity scale-model engine simulator tests in wind tunnels. The tests clearly demonstrated the achievement of the 3-decibel fan noise reduction. Engines designed to take advantage of this innovation will represent a new paradigm in engine design and will open the door for the application of additional concepts for noise reduction in engines.

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3.4 Jet Noise Reduction

Scale-model tests of advanced exhaust mixers in a high-fidelity wind tunnel have shown jet noise reduction of 3 decibels for a range of engine types, including separate flow engines. The mixers are exhaust nozzles that have been formed into complex shapes designed to enhance the mixing of the core, bypass, and ambient airflows to reduce jet noise. Although mixers have been in use, the innovation in these results was an improved design method, which incorporated numerically predicted flow physics to guide the noise reduction design and optimize engine performance. Such methods expand the understanding of the mechanisms of noise sources and ultimately extend the benefit of the developed technology to many different applications. In addition to these scale-model test results, a 3-decibel jet noise reduction was also achieved during an Allied-Signal static test

of a full-scale engine. The developed technology is being considered for industry designs and will likely be on production engines early this century.

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3.5 Liner Acoustics

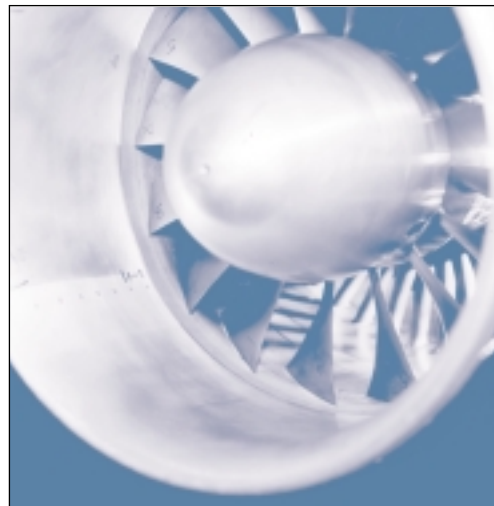
Jet engine nacelles or cowlings are equipped with liners to partially absorb fan tones before they propagate outside the engine. Typical liners today reduce community noise impact by 4 decibels. The goal of NASA research is to improve this by another 2 decibels. Recent research results have affected the whole liner design process, from determining the optimal acoustic properties of the liner (which must operate in the extreme flow conditions inside an engine) to validating that the desired properties have been achieved. The improved design process was validated in a wind tunnel test of a high-powered model fan where half of the goal, or a 1-decibel liner improvement, was achieved. Model and engine static tests are in progress to validate other innovations with the potential to achieve the full goal.

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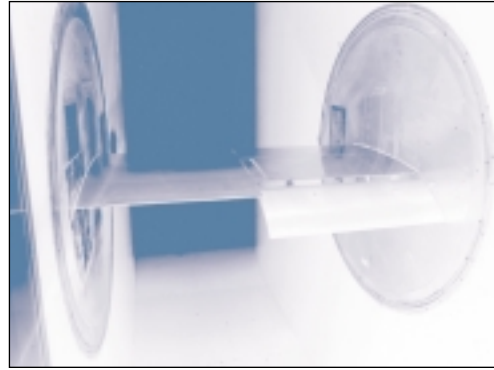
*(Bottom, Left) Model Jet
Noise Reducing Advanced
Exhaust Mixer*



*(Bottom, Right) Advanced
Nacelle Wind Tunnel Model*

3.6 Airframe Noise Reduction

During an aircraft approach, the noise the community hears is more than just the engine. Airplanes take off and land at slow speeds of 140 to 180 knots, compared with cruise speeds of 550 knots. To ensure adequate lift and stall margin during the critical take-off and landing, wings are enhanced with such lift-enhancing systems as trailing-edge flaps and extendible slats on the wing's leading edge. Exposed edges and gaps of high lift systems, not to mention the deployed landing gear, create airframe noises that can be as loud as the engines. NASA has developed a flow-physics-based technology that reduces the noise created by the air passing over flap edges. This technology is a micro piece of hardware that can be easily added to existing airplanes. The technology has been validated in small-scale-model tests and full-scale numerical simulation. Flap airframe noise reductions of 4 decibels have



been demonstrated experimentally with little degradation in lift performance. Not only can adoption of this technology benefit the community, but it can also aid the airline industry in meeting the more stringent noise certification standards of the future.

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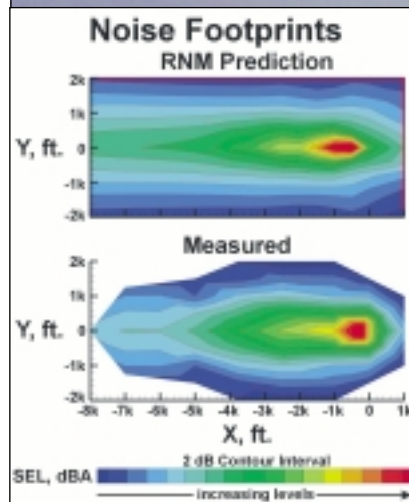
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(Top, Right) Flap
Airframe Noise Model
in Wind Tunnel

(Bottom) A tilt rotor
aircraft is used in tests
that compare noise
“footprints” predicted
using the Rotorcraft
Noise Model with
measured values.
Comparisons show
good agreement,
helping to validate
the prediction model.



3.7 Rotorcraft Noise Reduction

Currently, noise pollution is a topic of considerable interest, especially near airports and vertiports. Construction of a new airport or vertiport—or even the introduction of a new aircraft type at an existing facility—requires that an Environmental Impact Study be performed. To assess the impact on a

nearby community, Environmental Impact Studies and Land Use Planning Assessments require estimates of the noise footprints that will be generated by aircraft using a facility. Measuring the noise footprints directly for every aircraft under numerous operating conditions would be extremely expensive.

The Rotorcraft Noise Model (RNM), developed by Wyle Laboratories under contract to NASA, was tested and validated in FY 1999. It is a tool for predicting ground noise footprints generated by rotorcraft. RNM can predict the ground noise footprint for complex flight profiles if given the noise characteristics of a vehicle under a variety of operating conditions. The input noise characteristics can be acquired from existing databases; measured in a simpler, less costly flight test; or generated using an aeroacoustic prediction code. RNM can also be used as a research tool to design flight procedures for noise abatement. The adverse impact on a community adjacent to a facility can be reduced by tailoring flight procedures to minimize the noise exposure at given locations around the facility. These noise abatement or “fly neighborly” flight procedures can improve the quality of life for people living near airports/vertiports by reducing their exposure to high noise levels.

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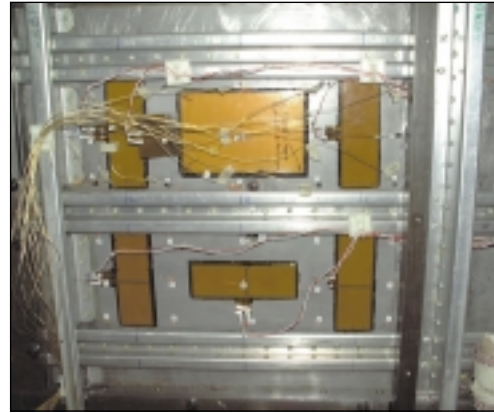
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3.8 Cabin Noise Reduction

NASA researchers have succeeded in demonstrating aircraft cabin noise reduction using a hybrid noise control technology that leverages active noise control with a detailed knowledge of structural dynamics. Termed Active Structural Acoustic Control (ASAC),



the technology improves noise controller performance by attacking aircraft interior noise closer to its source: fuselage structural vibrations. In addition, ASAC control technology reduces noise levels without the weight penalty that is associated with conventional, passive noise reduction methods. Research data obtained so far has indicated that ASAC controllers can deliver competitive noise reduction even though they use less power and fewer control channels than classic active noise controllers. This translates to lower cost noise control systems for our aerospace industries.

The capability of the ASAC technology was demonstrated in two experiments. First, a wind tunnel test demonstrated ASAC control of sound generated by the random action of subsonic and supersonic turbulent flow on an aircraft sidewall. Second, in a flight test using a Beech 1900D turboprop aircraft, an optimized array of structural actuators reduced cabin noise from the propeller by more than half. These technologies will enable the use of more effective and efficient structural designs for a range of aerospace vehicles.

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(Top, Right) Piezoceramic actuators provide the driving force to control sound radiating from an aircraft fuselage panel during a supersonic wind tunnel test. This is the first-ever demonstration of active control for interior cabin noise induced by supersonic turbulent boundary layer flow.



Environment: Aircraft Emissions Reduction

Although noise concerns have previously been the greatest environmental constraint to aviation's growth, more recent concerns about the impact of aviation air emissions on air quality and climate change are also threatening to limit operations.

In response to air quality concerns, the International Civil Aviation Organization (ICAO) continues to promulgate increasingly stringent standards for emissions during landing and takeoff. In the U.S., regulations under the Clean Air Act have resulted in local authorities, as well as environmental interest groups, demanding action from federal agencies and the air carriers to reduce emissions of nitrogen oxides (NO_x), which contribute to toxic ozone production, and other pollutants. The Kyoto Protocol to the UN Framework Convention on Climate Change has, in particular, drawn growing attention to aviation's emissions of carbon dioxide (CO₂). At the request of ICAO, a special report on *Aviation and the Global Atmosphere* was recently published by the Intergovernmental Panel on Climate Change (IPCC) and will serve as the basis for policy

to control aircraft cruise emissions in the near future.

Cruise NO_x emissions are also a climate concern, as these produce ozone and also control the concentration of methane, both potent greenhouse gases in the upper atmosphere. In addition, recent observations of aircraft contrail behavior have drawn attention to aerosol and particulate (e.g., sulfur, soot) emissions, which are suspected of producing high altitude cirrus clouds that adversely affect Earth's climate. Continued scientific assessment and development of safe and affordable technology options for reducing aircraft engine emissions are important, therefore, to protect the environment and to sustain the growth of aviation. Proposed NASA research and technology objectives are to reduce NO_x emissions by a factor of 3 within 10 years and by a factor of 5 within 25 years. The program will focus on developing low emissions and efficient combustors that operate at high pressures and temperatures, while maintaining high levels of engine operability and maintainability. Overall engine efficiency and related CO₂ improvements will also be

sought, for example, through performance improvements and weight reductions resulting from fewer compressor stages, advanced materials, and supporting subsystems.

The FAA's responsibility will be to develop and implement near-term programs to mitigate the effects of aircraft engine emissions. An important aspect of that job is the development of computer models that give insight into the system-wide consequences of alternative courses of action. Implementation of those models will allow local and national authorities to assess mitigation measures that contribute to improvements in local air quality, and also improve the understanding and mitigation of global climate change.

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4.1 FAA Emissions and Dispersion Modeling System

The Emissions and Dispersion Modeling System (EDMS) was developed in the mid-1980s as a complex source microcomputer model designed to assess the local air quality impact of proposed airport development projects. In response to the growing needs of the local air quality analysis community and changes in regulations (e.g., Conformity requirements from the Clean Air Act Amendments of 1990) the FAA, in cooperation with the United States Air Force (USAF), re-engineered and enhanced EDMS as Version 3 in 1997. EDMS Version 3 was re-engineered under the guidance of a government/industry advisory board composed of experts from the scientific, environmental policy, and analysis fields.

EDMS is designed to assess the local air quality impact of airport emission sources, particularly aviation sources, which consist



of aircraft, auxiliary power units, and ground support equipment. EDMS also offers a limited capability to model other airport emission sources that are not aviation-specific, such as power plants, fuel storage tanks, and ground access vehicles.

EDMS features the latest aircraft engine emission factors from the International Civil Aviation Organization (ICAO) Engine Exhaust Emissions Data Bank, vehicle emission factors from the Environmental Protection Agency's (EPA) MOBILE5a, and EPA-validated dispersion algorithms.

Since 1993, EDMS has been an EPA "Preferred Guideline" model for use in civil airports and military air bases. In 1998, the FAA revised its policy on local air quality modeling procedures for aviation sources, to ensure consistency and quality in performing aviation air quality analyses. The revised policy identified EDMS as the required (i.e., instead of preferred) model to perform local air quality analyses for aviation sources. The FAA continues to enhance the model under the guidance of its government/industry advisory board, to more effectively determine emission levels and concentrations generated by typical airport/air base emission sources.

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4.2 Atmospheric Effects of Aviation Project (AEAP)

Aircraft engine emissions affect climate change in three ways that are expected to increase in concern as aviation grows:

- ◆ From the burning of fossil fuels, aircraft produce about 3 percent of annual global emissions of carbon dioxide (CO₂), the most important greenhouse gas. There is good scientific understanding of the impact of these emissions, which is the same as for CO₂ at the earth's surface, such as from autos or power plants.
- ◆ At high altitudes (25,000 to 50,000 feet), nitrogen oxide (NO_x) emissions affect the production of ozone and the concentration of methane, both potent greenhouse gases for which a fair scientific understanding has developed.
- ◆ The third effect results from emissions of aerosol and particulate matter at high altitudes, and can be observed by the apparent increased incidence of cirrus clouds and the persistence of contrails, which influence the radiative character of the atmosphere. There is increasing knowledge about these effects, but poor scientific understanding.

The NASA Atmospheric Effects of Aviation Project (AEAP) conducts focused laboratory experiments, computer modeling, and field observations that support periodic assessments of aviation's impact on climate change. These assessments are being used as a basis for national and international policy. Most recently, AEAP was a major contributor to the Special Report on Aviation and Global Atmosphere by the Intergovernmental Panel on Climate Change.

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4.3 Low NO_x Emissions Technology

The environmental elements of NASA's Advanced Subsonic Technology and High Speed Research programs focused on experimental and analytical research to advance the understanding of emissions formation in combustion processes in advanced engine cycles. Engine emittants include oxides of nitrogen, speciation of hydrocarbons (CO, CO₂, and UHC, etc.) and sulfur oxides, and carbon-based gaseous or liquid particulates. Experimental work included advanced low-emission low-cost fuel injectors, advanced diagnostics to characterize emissions, and advanced technologies for measuring chemical kinetic and aerosol particulates. Analytical work includes the development of analytical models for turbulence-chemistry interaction, supercritical spray, and radiation.

In collaboration with the U.S. industry, NASA has contributed to the advancement of low-emission combustion systems for aircraft engines. A 50 percent reduction in NO_x emissions (compared with 1996 ICAO baseline) has been demonstrated in sector combustors for advanced subsonic engines at NASA. A 90 percent reduction in NO_x emissions (compared with today's production engines) has been demonstrated in sector combustors for supersonic engines at General Electric. These advanced combustor



(Bottom, Right) 60 degree, dual annular, TAPS sector built up in test rig. This low pressure sector used to test low power emissions, ignition, and lean stability.

Shown in Mod 1 configuration, currently being reconfigured to Mod 2 for testing in April.

technologies include lean, direct injection for subsonic engines and lean premixed, prevaporization for supersonic engines.

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4.4 Ceramic Matrix Composite (CMC) Combustor Liner

A significant challenge in achieving ultra-low NO_x combustor goals is the development of advanced high-temperature combustor liner materials requiring little or no film air cooling. Add to this requirement a combustor life goal of 18,000 hours, and you have a major durability challenge. NASA's High Speed Research (HSR) program has developed an advanced silicon-carbide-fiber-reinforced silicon carbide (SiC/SiC) Ceramic Matrix Composite (CMC) as a promising liner material for an advanced, ultra-low NO_x combustor. Various enabling technologies contributed to the successful development of a CMC liner material. These include development of (1) advanced silicon carbide fiber with high-temperature stability, (2) a new fiber coating, (3) a new fabrication technique for producing dense composites, and (4) an environmental barrier coating for preventing surface recession. Further development of CMC liners for higher temperature and pressure capabilities will lead to applications in a wide range of low-emission combustor designs.

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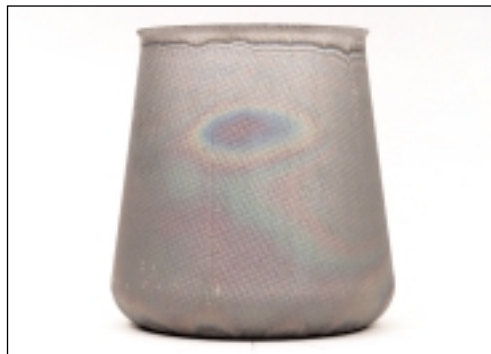
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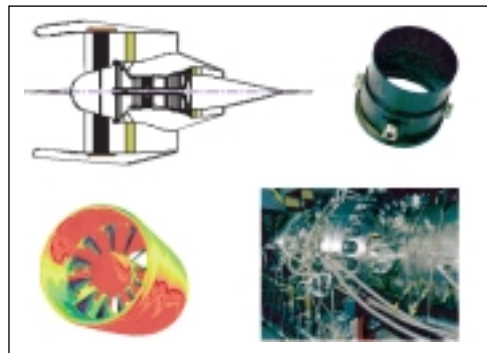
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(Bottom, Left) This CMC material has demonstrated a greater than 9000-hour life at 2200 degrees Fahrenheit in laboratory test cycles typical of aircraft engines.

(Top, Right) NASA's Ultra Efficient Engine Technology Program will improve air quality around airports.



4.5 Ultra Efficient Engine Technology Program



NASA's role in civil aeronautics is to develop high risk, high payoff technologies to meet critical national aviation challenges. Currently, a high priority national challenge is to ensure U.S. leadership in aviation in the face of growing air traffic volume, new safety requirements, and increasingly stringent noise and emissions standards.

The primary objective of the new Ultra-Efficient Engine Technology Program is to address two of the most critical propulsion issues: performance/efficiency and reduced emissions for a wide range of applications, both civil and military. High performance, low emissions engine systems will lead to significant improvements in local air quality and have a minimum contribution to ozone depletion, which will result in an overall reduction in aviation's contribution to global warming.

The UEET program will address local air quality concerns by developing technologies to reduce nitrogen oxide (NO_x) emissions by 70 percent at landing and take-off (LTO) conditions, from 1996 International Civil Aviation Organization (ICAO) standards. In addition, the UEET program will address potential ozone depletion concerns by demonstrating combustor technologies that prevent any discernible aircraft impact on the ozone layer during cruise operation (up to a 90 percent reduction). This program enables the U.S. to be competitive in developing very low emissions propulsion systems.

Additionally, the UEET program will address the impact of projected aviation

growth on the climate by providing critical propulsion technologies for a dramatic increase in efficiency. This increased efficiency will enable reductions of carbon dioxide (CO₂) emissions based on an overall fuel savings goal of about 15 percent for large subsonic transport or as much as 8 percent for supersonic and/or small aircraft. Fuel savings represent significant cost benefits to the traveling public.

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4.6 Adaptive Performance Optimization

NASA on-board software, called Adaptive Performance Optimization, minimizes drag and saves fuel through small movements of outboard ailerons during cruise flight. These movements give the aircraft's wings the most efficient, or optimal, airfoil shape.

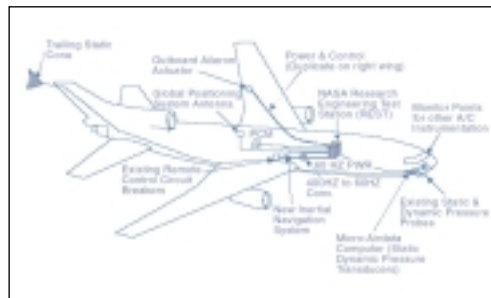
Reduction of drag can have a major impact on airline profit margins: For wide-body transports, a one percent reduction in drag could save \$140,000 per aircraft per year in fuel cost. Many aircraft must fly with less than a full payload because of factors like route length, higher than normal airport altitude (e.g. Denver), and hot summer temperatures. For these aircraft, a one percent reduction in drag can be used to trade payload for fuel that can be worth up to \$4,000,000 in increased revenue per aircraft per year.

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4.7 Electrically Powered Actuators

Three advanced, electrically powered actuators, flight validated on a NASA F-18, will lead to more electric designs for future aircraft, reducing reliance on an aircraft's central hydraulic system. Adopting electrically powered actuators for all flight control surfaces could lead to a 5 to 9 percent fuel savings on an all-electric passenger plane and a 30 to 50 percent reduction in ground equipment.



A follow-on version of one of the actuators is being used on the space flight-rated X-38 Crew Return Vehicle technology demonstrator and is being developed for the X-33 reusable launch vehicle technology demonstrator. Electric actuators are being considered for the primary flight control surfaces on a Joint Strike Fighter candidate as well.

Partners in the Electrically Powered Actuation Design program were the Air Force Research Laboratory, the Naval Air Warfare Center Aircraft Division, and NASA.

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4.8 Unleaded Fuels Program

As a result of the mandates of the 1990 Clear Air Act, the FAA initiated unleaded fuel research and engine and fuel testing. Such testing is being conducted in cooperation with an FAA and industry-established Coordinating Research Council (CRC) Committee, to address issues such as engine detonation, material compatibility, volatility

(Bottom, Left) Elements of an Adaptive Performance Optimization system.



(vapor lock), engine performance, storage stability, water reaction, emissions, fuel consumption changes, and durability (engine and component life).

Engine and fuel tests are currently being conducted to validate the octane requirement that is acceptable for engines within the existing general aviation fleet. At the conclusion of these tests, minimum octane requirements for candidate unleaded fuel formulations will be specified as a development goal for participating oil companies within the CRC Committee. The FAA will then evaluate these fuels through a series of performance- and safety-related engine fuel tests.

Data from these tests will aid the FAA in certifying the existing fleet of general aviation aircraft on a replacement fuel, and in developing a specification with the

American Society of Testing and Materials (ASTM) for an unleaded aviation gasoline to replace the currently available 100-octane low-lead fuel. This specification, in turn, will serve as a basis for the development of advisory material covering the certification of new piston-powered engine designs and their application to the performance of new general aviation airplanes. Further testing at the FAA's small-engine test facilities is anticipated, to define the safety and performance of other critical in-service aircraft engines that have not been tested with the newer unleaded fuels, as well as to develop other new or alternative fuels.

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General Aviation

A national challenge for ever-safer accessibility to more destinations is emerging at the threshold to the 21st century. That challenge is driven by the emerging gap between the demand and the supply for safe, convenient, affordable transportation. This demand cannot be satisfied by the planned investments in the hub-and-spoke and highway systems alone.

Revolutionary developments already under way in general aviation technology and training may lead to a whole new way of travel. NASA, DOT, FAA, the States, and industry can help make this happen by working together to create a Safe Small Aircraft Transportation System.

5.1 Safe Small Aircraft Transportation System

A Safe Small Aircraft Transportation System would provide safe accessibility in nearly all weather conditions throughout virtually all of the nation's suburban, rural, and remote landing facilities, including those communities that cannot be economically served by

airlines. Safe, affordable, and easy-to-use personal aircraft can reduce typical inter-city travel times by 75 percent. The emerging gap between demand and supply for inter-city transportation could be met through this capability, *if the safety challenges can be met.*

The ingredients exist to enable safe and affordable air transportation using smaller aircraft operating between thousands of smaller airports. These ingredients include "Information Age" aircraft with capabilities for virtual "Highway in the Sky" operations. An "interstate skyway" system can integrate a network of thousands of smaller, underutilized airports and airspace for such "smart aircraft" to operate safely in most weather conditions. To date, no national investments have been funded to integrate the vehicle and infrastructure technology development opportunities toward a unified transportation system-driven concept.

The solution to this challenge requires both technologies and public policy. The technology challenges can be affordably addressed through enhanced research capabilities and



full potential, new transportation system capabilities are required.

The Safe Small Aircraft Transportation System can satisfy a large portion of the demand for Information Age accessibility. This effect is particularly vital for smaller communities in the states that cannot expect to have accessibility to large airports or interstate highways. The American public will benefit in both quality of life and standard of living to a degree not seen since we put “wheels on America” in the 20th century.

partnerships between NASA, the FAA, industry, universities, and the States. A federal, state and local government partnership can address the public policy challenges for development and deployment of “smart airports” for SATS.

The result can revolutionize the safety of smaller aircraft and airports for service in the nation’s air transportation system. In the process, certain categories of causes of fatal accidents can be virtually eliminated for the next generation of travelers and pilots.

As the Information Age unfolds, a new economy is emerging, driven by knowledge-based industrial development and the Internet. However, the impending saturation of the hub-and-spoke and highway systems will limit this economic expansion to hub-and-spoke locations. For eCommerce and the new highly-networked economy to reach its

The Safe Small Aircraft Transportation System can unleash the full potential of eCommerce’s effect on standard of living and quality of life by distributing economic opportunities in more equitable ways throughout the nation’s smaller and rural communities. The concept would represent an exportable transportation innovation that relieves the current pressures on existing ground and air systems, land use, and environmental issues.

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5.2 NASA General Aviation Program

The goal of the NASA General Aviation Program is to reduce public travel times by



(Top, Left) Safe accessibility in smaller aircraft throughout suburban, rural, and remote landing facilities.

(Bottom) Artist’s conception of possible next-generation general aviation aircraft.

half in 10 years and by two-thirds in 25 years. To accomplish this goal, NASA and its partners have invested in the revolutionary technologies necessary not only to build the next generation of vehicles for business and personal air transportation but also to train the average person to operate them safely. To bring this type of transportation capability to the average person, the vehicles must be easier and safer to operate, and the related training simplified and reduced in cost (both in time and money).

Among the advancements in development are innovative, low-cost engines; graphical, easy-to-read displays; energy absorbing, crashworthy structural elements; and additional safety features including airbags and better restraint systems. NASA recently led the effort to qualify improved structural materials for general aviation aircraft by defining the methodology for epoxy-based pre-impregnated composite materials. This has resulted in a substantial reduction in certification cost (\$500,000 per component) and certification time (two years per component).

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5.3 The Highway-In-The-Sky Display (HITS) System

An ergonomically designed flight situation display system that replaces the old-fashioned instrument panel is the hallmark of the NASA Advanced General Aviation Transportation Experiment (AGATE) cockpit revolution. The display system is the foundation for NASA's Highway in the Sky (HITS) initiative, which is developing affordable glass cockpits for single-engine, single-pilot airplanes by the year 2001.

The HITS display will project a pre-planned course "highway" for the pilot to follow, instead of gauges and dials for the pilot to interpret and synthesize into a mental picture of the airplane situation. The graphical display system includes a two-panel display of Global Positioning System (GPS) position and attitude, course, weather depiction, and aircraft track and performance. The integrated flight display system provides the pilot with an intuitive pictorial for situational awareness, and with a system that is affordable for a wide spectrum of general aviation aircraft. The pilot will use the highway display to guide and control the airplane intuitively.

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(Bottom) The general aviation cockpit of the future would include NASA's Highways in the Sky technology.

5.4 General Aviation Propulsion Project

NASA's General Aviation Propulsion (GAP) Project is a partnership between NASA and the aircraft industry to bring a new era to small aircraft by developing and flight demonstrating revolutionary low-cost new aircraft engines in the year 2000. These radically advanced engines will form the basis for the general aviation industry to produce similarly advanced affordable engines for the commercial market soon after the GAP program is completed.

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Intermittent Combustion Engine:

Teledyne Continental Motors and their industry team, in cooperation with NASA, have developed a highly advanced 200-hp compression-ignition piston engine. The engine uses jet fuel and is designed to be priced at half the cost of current engines. Careful design consideration has been given to making this engine the smoothest and quietest piston engine to ever have flown in a general aviation aircraft. The engine has been designed, and proof-of-concept engines are now undergoing extensive ground testing. A flight engine is being prepared for installation in a Cessna 337 aircraft, and it will be demonstrated by the end of 2000.

Turbine Engine:

Williams International and their industry team, in cooperation with NASA, have designed a radically new turbofan engine that will be significantly less expensive than current aircraft turbofan engines, making turbine engines affordable for small general aviation aircraft. This engine, known as the FJX-2, is a high bypass ratio turbofan that will produce 700-lbs. thrust but weigh less than 100 pounds. The FJX-2 has been designed to maintain excellent turbine engine performance characteristics while being competitive in price with comparable piston engines. Several proof-of-concept turbofan engines have been ground tested.

Testing, including simulated high-altitude operation, will continue through the year to prove out the design. Williams International has entered a venture with Eclipse Aviation Corporation to provide commercial versions of the FJX-2 engine, the EJ-22, for the Eclipse 500, a new six-place jet.

5.5 Safe Flight 21

The Safe Flight 21 program is a joint government/industry initiative designed to demonstrate and validate, in a real-world environment, the capabilities of advanced communication, navigation, and surveillance, and air traffic procedures associated with free flight. The program will demonstrate the following free flight operational enhancements selected by RTCA, using automatic dependent surveillance-broadcast (ADS-B) as an enabling technology:

- ◆ Weather and other information in the cockpit.
- ◆ Affordable means to reduce controlled flight into terrain (cfit)
- ◆ Improved capability for approaches in low visibility conditions
- ◆ Enhanced capability to see and avoid adjacent traffic
- ◆ Enhanced capability to delegate aircraft separation authority to the pilot
- ◆ Improved capability for pilots to navigate airport taxiways
- ◆ Enhanced capability for controllers to manage aircraft and vehicular traffic on the airport surface
- ◆ Surveillance coverage in nonradar airspace
- ◆ Improved separation standards

The Safe Flight 21 program will also take the following into account over the course of demonstrating these nine operational enhancements: safety, efficiency, capacity, certification, pilot/controller situation awareness, human factors, spectrum, and affordability issues.

The potential market for ADS-B implementation is huge. If ADS-B, FIS-B, and TIS-B are included in the NAS Architecture, over 10,000 aircraft and thousands of ground stations may need to be equipped. The inter-

national marketplace is just as large. Success of the Safe Flight 21 demonstrations are critical to opening these markets up.



As an enabling technology, ADS-B will provide the means for airborne aircraft to broadcast their position to other aircraft and to ground stations. ADS-B avionics will periodically transmit aircraft location, altitude, velocity, and other data derived from either GPS or flight instruments via a digital link. Onboard aircraft, ADS-B information will be displayed on a multifunction display, such as a Cockpit Display of Traffic Information (CDTI). The intent of broadcasting this information is to increase the pilots' situational awareness of ADS-B equipped aircraft. ADS-B can also be used to provide air traffic controllers with a consolidated picture of the controlled airspace. The information provided to controllers will be more frequently updated than that provided by other surveillance equipment. In addition, ADS-B can be used as the enabling technology for Flight Information Services-Broadcast (FIS-B) and Traffic Information Services-Broadcast (TIS-B), which will allow weather and other data available on the ground to be provided to the cockpit. As a result, ADS-B capabilities have the potential to significant-

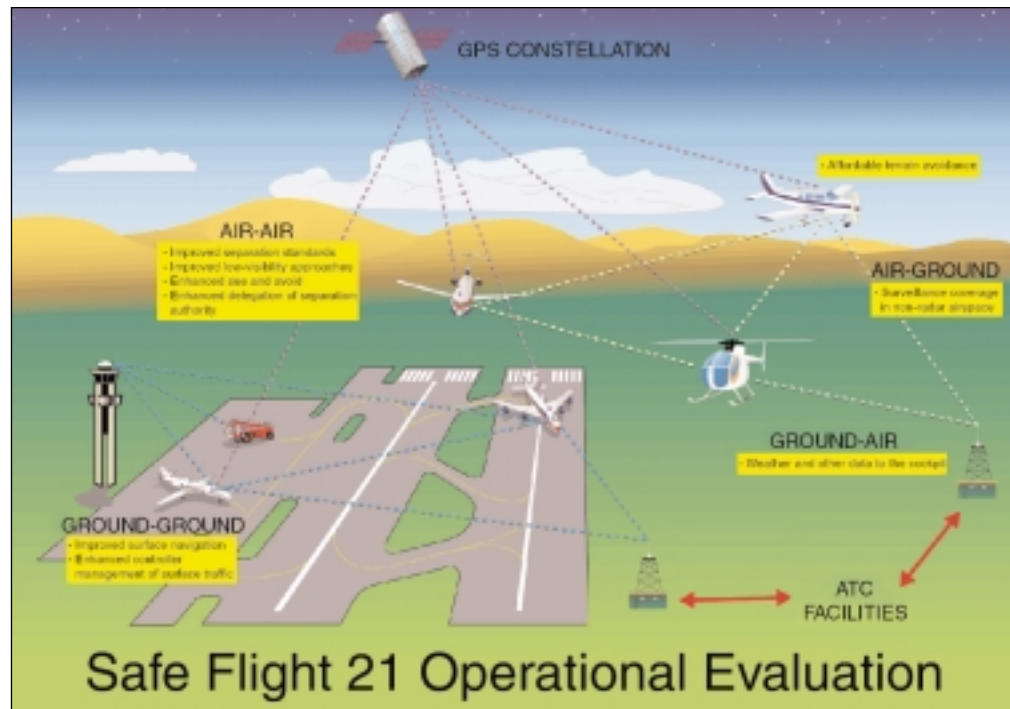
ly increase flight safety, system capacity, and overall efficiency of flight operations.

The Safe Flight 21 program is based on the principle that government and industry will share in the development of a global air transportation system, as we move into the free flight era.

The FAA is collaborating with industry via RTCA to ensure that the scope, resources, schedule, and execution of the Safe Flight 21 program reflects government/industry consensus. The vehicle for this collaboration is the RTCA Safe Flight 21 Steering Committee, which includes representatives from the Aircraft Operators and Pilots Association (AOPA), Air Line Pilots Association (ALPA), National Air Traffic Control Association (NATCA), Cargo Airline Association (CAA), U.S. Airways, United Airlines, Delta Airlines, and the FAA.

The FAA and the CAA are entering into a partnership to pool their resources, in a collaborative effort to conduct an operational evaluation of ADS-B capabilities in the Ohio Valley. The CAA began equipping its aircraft in late 1998 as a prelude to in-flight evaluations, focusing on the air-air use of the equipment for "see and avoid" applications. A subsequent operational evaluation, during Summer 1999, employed both avionics and ground stations to demonstrate expected operational enhancements from ADS-B, including the broadcast of TIS and FIS information, and at the same time gathered critical data on the three candidate ADS-B links (Mode Select (Mode S) Extended Squitter, Universal Access Transceiver (UAT), and VHF Data Link (VDL)(Mode 4)), and operational procedures.

Through the "Capstone" initiative, the FAA is working with air carriers in the area of Bethel, Alaska, to improve aviation safety while offering greater efficiencies to operators. "Capstone" will concentrate on the evaluation and implementation of three operational enhancements in the region: Weather and Other Information in the Cockpit, Affordable Means to Reduce CFIT, and Enhanced Capability to See and Avoid



Adjacent Traffic. An initial operational evaluation occurred during summer 1999, with limited equipment and subsequent operational evaluations following in 2000.

The FAA is working with United Airlines to evaluate Paired Approach and Runway Incursion Protection ADS-B applications at San Francisco. Simulation studies have been performed, and an operations concept is being developed; Further operational evalua-

tions of these applications are currently in the planning stages. The FAA has started soliciting inputs from major potential avionics providers on how to make ADS-B equipment affordable enough to promote widespread voluntary equipage.

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Aviation Security

Every time you enter an airport, walk through an airport metal detector, board an aircraft, fly across country, or retrieve your luggage from an airport conveyor belt, you come in direct contact with the work of the Federal Aviation Administration's aviation security research and development professionals. The FAA's security work encompasses the total civil aviation environment, including airports, aircraft, support facilities, related equipment, and people—not only passengers, but also employees, visitors, and vendors.



The FAA is the lead agency for all U.S. Government research in the area of explosives and weapons detection. Today, it is faced with the challenge of countering the increasing sophistication of terrorists by developing and using superior technology and systems designed to thwart terrorist activities and render ineffective terrorist attempts to sabotage civil aircraft.

The FAA has created an aggressive security research and development program dedicated to developing, testing, and deploying new aviation security technologies to airports and air carriers around the world. This program conducts research, development, and test and evaluation activities in the areas of explosive

(Bottom, Left) Deployed security equipment used for detecting explosives at airport checkpoints.



*(Top, Right) Determining the vulnerability of a pressurized L1011 aircraft.
(Jan. 1998)*

and weapons detection for checkpoint, checked luggage and cargo, human factors, aircraft hardening, and airport security technology integration.

The agency's research and development efforts identify and perfect new technologies for predicting, detecting and mitigating threats. Security is being enhanced already, through a combination of several different aviation security technologies into a single system. By 2010, integrated systems that are able to perform functions such as passenger screening will be contained in a single-package element, and these integrated elements will be combined into an integrated system that will constitute the security system of the future.

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6.1 Checkpoint-for Passengers and Carry-On Luggage

Checkpoint security research is needed (1) to develop and improve technologies to prevent the introduction of threats such as improvised explosive device components and weapons that may be concealed on persons or in carry-on items, and (2) to integrate, as operationally suitable, the developed technologies. The Aviation Security Laboratory identifies, develops, and prepares for deployment technologies to detect threats at airport checkpoints and develops methods to improve screener performance.



Currently the laboratory is researching methods to improve existing technologies by reducing false alarm rates, improving throughput of people in the checkpoint, and improving throughput of bags using an integrated system. The object of this research is to eliminate threats onboard aircraft, reduce fatalities, and decrease the catastrophic financial loss from a sabotaged plane, considering the cost of the Pan Am 103 tragedy estimated at \$1.5 billion.

Products evaluated, deployed, or under development for checkpoint security include:

- ◆ IonScan 400 by Barringer Instruments
- ◆ Itemizer by Ion Track Industries
- ◆ CPAD Orion and CPAD Orion Plus by CPAD Technologies
- ◆ EGIS 3000 by Thermedics
- ◆ EGIS II by Thermedics



*(Bottom, Left) Ion Track
Itemizer*

*(Top, Right) Barringer
Document Scanner*

*(Bottom, Right) Ion Track
Instrument Portal*



(Bottom, Left) CTX 5500
Invision Technologies

(Top, Right) eXaminer, L-3
Communications

- ◆ Document scanner by Barringer Instruments
- ◆ Access Control Monitor by Ion Track Industries (prototype)
- ◆ Sandia Portal by Sandia Labs (prototype)
- ◆ SecurScan Portal by Thermedics (prototype)
- ◆ Dielectric Portal by Spatial Dynamics (prototype)
- ◆ ITI/Penn State Portal (prototype)

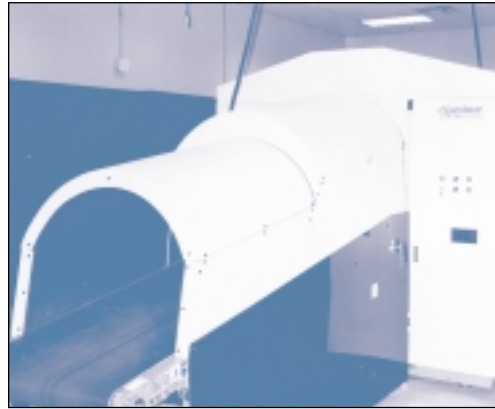
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6.2 Checked Luggage

The goal of research in the checked luggage area is to develop and improve technologies to prevent the introduction of improvised explosive devices, weapons, and other threats concealed in checked items and integrate them into an airport environment. The mission of the Aviation Security Laboratory is to identify, research, develop, evaluate, and test technologies, procedures, and detection systems for checked luggage.



Security personnel in the checked luggage area are currently researching methods to reduce the cost of security equipment, reduce false alarm rates, and improve effective throughput of existing technology. The object of this research is to eliminate threats onboard aircraft, reduce fatalities, and decrease the catastrophic financial loss from a sabotaged plane.

Two vendors whose products met the rigorous certification criteria for explosive detection systems are Invision Technologies and L-3 Communications.

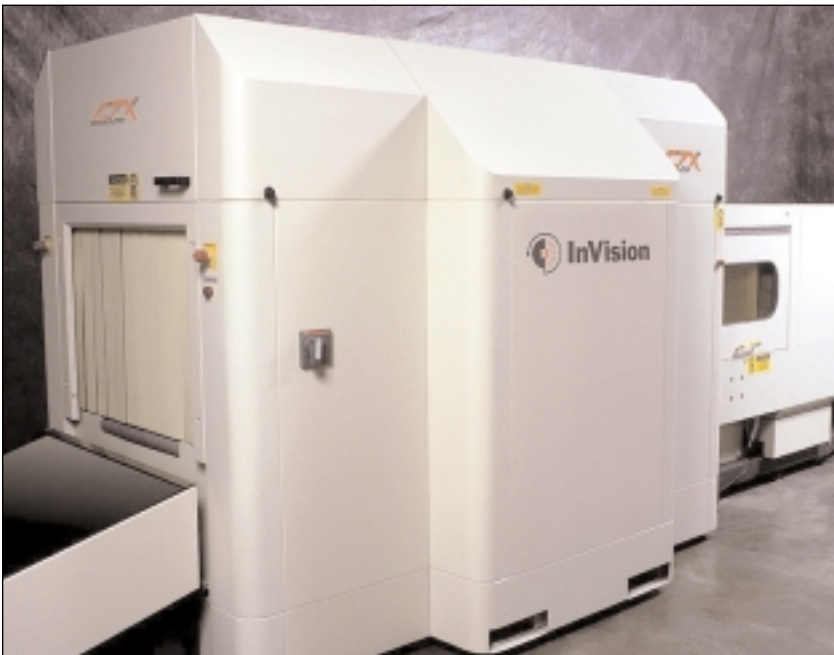
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6.3 Cargo

Cargo security research is needed to prevent the introduction of improvised explosive devices concealed in cargo and mail that is transported on passenger aircraft. Methods to achieve this include improvement in the efficiency and effectiveness of prescreening (profiling) for shipped items, enhancement of the security effectiveness of point-to-point ground transit of prescreened items, and improvement in the equipment used to detect improvised explosive devices, as well as enhancement of their efficiency. Cargo security personnel identify, develop, and prepare



for deployment technologies for detecting explosive threats in the cargo vector, and develop and validate methods to improve threat detection.

The object of the cargo security program are is to eliminate threats onboard aircraft, reduce fatalities, and decrease the catastrophic financial loss from a sabotaged plane.

Products developed for cargo security include:

- ◆ Computer-assisted profiling systems
- ◆ Enhanced protocols for ground transit of cargo along the shipper-forwarder-air carrier supply chain
- ◆ Cargo-screening feasibility studies using nuclear and trace technologies
- ◆ Evaluation of cargo inspection systems for break-bulk and containerized/palletized cargoes.

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6.4 Airport Security Technology

The airport security technology integration program focuses on security of the airport environment and security of FAA facilities, equipment, and communications. Major program areas include personnel access, physical security, systems engineering related to equipment operational suitability, positive passenger bag matching, decision-support tools such as Blast/FX, passenger and baggage flow, and risk or vulnerability assessments. The goals of the program are to improve security of airports and security of National Airspace System facilities, to develop a Civil Aviation Security system architecture, and to enhance total system effectiveness.

Currently, the laboratory is examining methods to analyze airport security via PC-based tools and methods to monitor airport security

and integrate with other airport control functions. Airport security goals are to improve the prediction of airport security needs, reduce the cost of security equipment, and improve the effectiveness of perimeter and physical security.

Benefits of this research are to improve airport security planning capabilities, to reduce life cycle costs for airport and air carrier security and to minimize threats onboard aircraft, reduce fatalities, and decrease the catastrophic financial loss from a sabotaged plane.

Products developed through airport security technology research include:

- ◆ Blast/FX Modeling Tool for estimation of explosive damage to air terminals and passengers
- ◆ Positive Passenger Bag Match technology
- ◆ Risk management methodology for airport vulnerability and risk self-assessment
- ◆ Revised "Recommended Security Guidelines for Airport Planning, Design and Construction"

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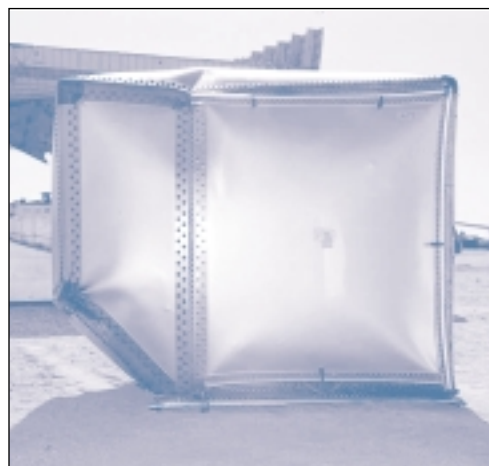
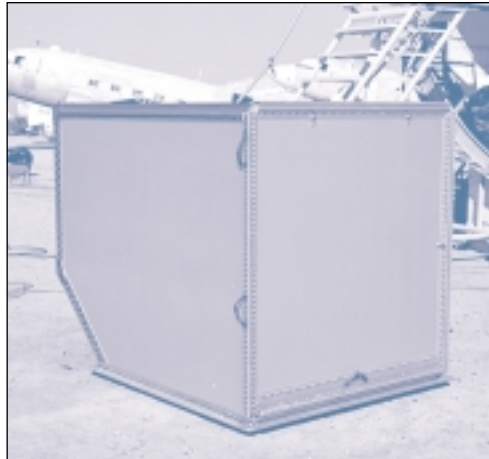
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6.5 Aircraft Hardening

The aircraft hardening program is responsible for validating the detection standards in terms of commercial aircraft vulnerability. The program seeks ways and methods of reducing or mitigating vulnerability.

Research focuses on finding ways to protect against advanced terrorist threats, and developing methods to reduce aircraft vulnerability to internal explosions, electromagnetic high-energy signal interference, and man-portable air defense systems.

The Aviation Security Laboratory is conducting research to identify the minimum size



explosive that can result in aircraft loss, and developing methods and techniques to reduce vulnerability to other outside means of attack. Research also seeks to identify practical security countermeasures for threats and to identify documented data on vulnerability to explosives.

Research is conducted to provide data packages in support of rule making, with the objective of increasing survivability of commercial aircraft against explosives and other advanced terrorist threats. Goals of the program are to identify methods of mitigating threats, for example through the use of hardened luggage containers, and to increase effectiveness and reduce costs of these methods through operational and technical assessments. The objects of the Aircraft Hardening Program are to reduce fatalities and decrease the catastrophic financial loss from an act of sabotage against an aircraft.

(Photos) Galaxy Scientific Corporation Blast Resistant Luggage Container before and after blast test.

Products developed as a result of aircraft hardening research include:

- ◆ Blast-resistant luggage container
- ◆ Research assessment of explosive-resistant units for narrow-body aircraft
- ◆ Research assessment on the feasibility of hardening aircraft overhead compartments
- ◆ Vulnerability report for all types of aircraft
- ◆ Joint FAA-Department of Defense report on vulnerability to man-portable air defense systems.

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6.6 Aviation Security Human Factors

The Aviation Security Human Factors Program ensures that security systems are operating at peak effectiveness and efficiency. The program accomplished this by enhancing operator performance and addressing systems integration issues for new and emerging technologies. Outcomes of this research include methods to improve operator selection, training, and performance monitoring. Research also identifies ways to enhance equipment design to accommodate constraints due to manpower, training, human factors engineering, health, and safety considerations.

The goals of human factors research are to identify major system deficiencies, to make recommendations for resolving deficiencies, and to optimize screener performance. The objects of the program include reducing aircraft fatalities and decreasing catastrophic financial loss from a sabotaged plane.

Products developed to address human factors issues include:

- ◆ Screener selection testing
- ◆ Computer-based training

*(Photos) Aviation Security
Human Factors Research
Center, Hartsfield Atlanta
International Airport.*



- ◆ Threat-image projection
- ◆ Screener Readiness Testing
- ◆ Computer-based training modules for screener checkpoint remedial and recurrent training
- ◆ Functional requirements for screener selection, training, and performance monitoring for emerging detection technologies
- ◆ Determination of the knowledge, skills, and abilities needed for emerging detection technologies
- ◆ Selection tests, training, and performance monitoring techniques for emerging technologies



- ◆ Elevated Podium for Integrated Checkpoint Security Supervision (EPICSS)
- ◆ Development and testing of threat resolution procedures, using multiple technologies.

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Technology Transfer

Fostering cooperation between government and industry is an urgent requirement if the United States is to remain a world leader in developing innovative and leading-edge technologies. Technology transfer addresses this need for government-private sector cooperation by enabling companies, colleges and universities, and federal laboratories to work together to develop innovative technologies and marketable products.

More than \$70 billion annually . . .

That's how much the government invests in its laboratories for research and development (R&D). This investment created federal laboratories that produce advanced technologies that can serve not only government interests, but also the interests of the business and academic communities.

7.1 FAA's Technology Transfer Program: The Key to Economic Success

The goal of the FAA's Technology Transfer Program is to transfer knowledge, facilities, equipment, or capabilities developed by fed-

eral laboratories or agencies to the private sector to expand the United States technology base and to maximize the return on investment in federally funded research and development. The purpose of the Technology Transfer Program is to help the private sector meet the challenges of the highly competitive global economic environment, along with providing FAA personnel assistance in achieving critical R&D goals or meeting congressionally mandated research—in spite of limited R&D fund—that has a direct impact on aviation, the mission of the FAA, or on the civil aviation community.

You and the FAA as Partners . . .

FAA technology transfer provides an opportunity for your company or academic institution to tap into the endless resources that our laboratories have to offer. As a technology transfer partner with the FAA, you have access to our advanced technologies, our state-of-the-art facilities, and the expertise of our highly skilled scientists and engineers. This access can help you develop products and technologies that will be commercially successful and can help ensure long-term success for you.

Cooperative Research Development Agreements (CRDA)

If you are interested in R&D that is efficient, fast, and economical, a Cooperative Research and Development Agreement may be the right vehicle for you. A CRDA enables you and the FAA to share personnel, resources, services, facilities, and equipment for specific R&D projects. Through a CRDA, you will be able to utilize some of the most technologically advanced laboratories and test facilities in the world. A CRDA can also result in the development of intellectual property that you keep exclusively, while the Government retains a license for its use. The CRDA allows the FAA to share facilities, equipment, services, and personnel resources in cooperation with private industry, academia, or state/local government agencies. It is implemented to develop an idea, prototype, process, or product for direct application to the civil aviation community and/or indirect application for commercial exploitation.

Cooperative Research Programs

The FAA's cooperative research programs facilitate the exchange of personnel between the FAA and participating companies or colleges and universities, through such programs as the Technology Share program, the Independent R&D program, and the Small Business Innovation Research Program (SBIR). The SBIR Program seeks to encourage the initiative of the private sector and to use small business as effectively as possible in meeting federal research and development objectives. The purposes of the program are to stimulate technological innovation and to use small business to meet Federal research and development needs. Additionally, the SBIR Program is used to increase private sector commercialization of innovations derived from federal research and development and to foster and encourage minority and disadvantaged participation in technological innovation.

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7.2 NASA's Technology Transfer and Commercialization Program

Today, more than ever, advanced technology is the key to America's economic growth and development. NASA's Commercial Technology Network is at the forefront of developing relationships that allow aerospace expertise and technology to be incorporated into the private sector. As critical technologies for aerospace use are developed, NASA works with industry by co-developing, partnering, and licensing to commercialize these technologies and maximize their impact across the broadest range of applications.

NASA strengthened the Commercial Technology Network's Technology Transfer program in 1989 to make technology available to businesses, universities, and other government agencies. Working with national and regional technology transfer networks and our industrial partners, we reduce development costs, accelerate production schedules, and deploy existing technologies to points where they can make significant differences for both companies and individuals. By sharing technology with industry, NASA realizes two of its major goals: to strengthen America's competitiveness in the world marketplace and ensure future technological breakthroughs.

National needs for quality, durability, value, and environmental protection benefit from NASA's drive to improve on all these fronts. Across the agency, researchers are applying aerospace technologies in conventional and unconventional ways, stretching the boundaries and creating new applications for a host of new materials, processes, and inventions, many of which find their most promising uses outside the traditional aerospace applications.

NASA works directly with industry to develop many aircraft technologies, but we also develop technology for launch vehicles, spacecraft, rocket engines, pumps, turbines, nozzles, and injectors. Insulation, coatings, electronic components, and even software emerge from NASA's efforts in a steady

stream, and almost all are available for use by American industry.

As we move into the 21st century, NASA is seizing the technological high ground, and bringing the opportunities that come from it to America's industries and people. Following are brief examples of technologies developed for NASA applications outside of aeronautics. The commercialization of these technologies has provided benefits to the air transportation industry in a variety of applications. As examples, we have selected technologies that have been applied to airports and their operations.

Reusable Surface Insulation

Advanced Flexible Reusable Surface Insulation was developed by Ames Research Center to protect the Space Shuttle from the searing heat that engulfs it on reentry into the Earth's atmosphere. Hi-Temp Insulation, Inc., has adapted this Space Shuttle program technology for commercial use.

NASA-assisted improvements to the insulation material gives it the ability to withstand heating and cooling cycles, rapid and fluctuating temperature changes, continuous vibration and gravitational stress, and contact with aircraft engine contaminants.

A Fire Protection Division of Hi-Temp Insulation has been established, offering the first suit designed exclusively by and for aircraft rescue fire fighters. The suit offers great mobility, comfort, and flexibility while weighing far less than other heat-protecting apparel. From the inside out, the suit retards heat, scalding steam, flammable fumes, and molten liquids.

Thermal Packaging

Aluminized polymer film used in spacecraft as a radiation barrier to protect both astronauts and delicate instruments now has many different applications.

The packaging reflects outside heat away from contents inside the container. Spinoff applications of the material include aluminized shipping bags, food cart covers, medical bags, gel packs, insulated panels, and express mailers.

Airline Operations Aid

C Language Integrated Production System (CLIPS), a NASA-developed expert systems program, is used by American Airlines for three purposes: as a rapid prototyping tool; to develop production prototypes; and to develop production applications. An example of the latter is CLIPS' use in "Hub S1AAshing," a knowledge-based system that recommends contingency plans when severe schedule reductions must be made. Hub S1AAshing has replaced a manual, labor-intensive process. It saves time and allows operations control coordinators to handle more difficult situations. Because the system assimilates much of the information necessary to facilitate educated decision making, it minimizes negative impact in situations where it is impossible to operate all flights.

3D Audio System

Research into virtual reality led to the development of the Convolvotron (manufactured by Crystal River Engineering), a high-speed digital audio processing system that delivers three-dimensional sound over headphones. It consists of a two-card set designed for use with a personal computer. The Convolvotron's primary application is presentation of 3D audio signals over headphones. Four independent sound sources are filtered with large time-varying filters that compensate for motion. The perceived location of the sound remains constant. Possible applications are in air traffic control towers or airplane cockpits, hearing and perception research, and virtual reality development.

Traffic Monitor

The X-15 "Eye in the Sky," a traffic monitoring system, incorporates NASA imaging and robotic vision technology. A camera or "sensor box" is mounted in a housing. The sensor detects vehicles approaching an intersection and sends the information to a computer, which controls the traffic light according to the traffic rate. Jet Propulsion Laboratory technical support packages aided Mestech in developing the system. The X-15's "smart highway" can also be used to count vehicles on a highway and compute the number in each lane and their speeds, important information for freeway control engineers.



The new NASA software VISAR, can make valuable clues visible in videos taken in low light. The single frame image (top) taken at night was brightened, enhancing both details and noise, or snow. Then to further overcome the video defects in one frame, VISAR adds information from multiple frames to reveal a person. To create the clarified image (bottom), 50 frames of video which is less than 1 second on videotape were added together.

Additional applications are in airport and railroad operations. The system is intended to replace loop-type traffic detectors.

Environment Monitor and Explosives Detection

When Viking landers touched down on Mars equipped with a variety of systems to conduct automated research, each one carried a compact but highly sophisticated instrument for analyzing Martian soil and atmosphere. The instrument called a Gas Chromatography/ Mass Spectrometer (GC/MS) had to be small, lightweight, shock resistant, highly automated and extremely sensitive, yet require minimal electrical power. Viking Instruments commercialized this technology and targeted their primary market as environmental monitoring, and especially the monitoring of toxic and hazardous waste sites. Waste sites often contain chemicals in complex mixtures, and the conventional method of site characterization, taking samples on-site and sending them to a laboratory for analysis, is time consuming and expensive. Other terrestrial applications are explosive detection in airports, drug detection, industrial air monitoring, and medical metabolic monitoring for military, chemical warfare agents.

Airline Wheelchair

Few people who use wheelchairs travel by air because of the difficulties in moving through the airplane cabin. A cooperative program involving several organizations has led to a wheelchair that is capable of moving through the narrow aisle of an airliner to move passengers to their seats and give them access to the lavatories. One of the prototypes was designed by the University of Virginia Rehabilitation Engineering Center with help from NASA's Langley Research Center. Langley applied aerospace technology in structural analysis and materials engineering. The wheelchair is stable, durable, and easy to handle. It is made of composite materials, weighs only 17 pounds, and can support a 200-pound person. The chair folds easily for stowage when not in use.



A government, industry, and academic cooperative is developing an advanced hybrid electric city transit bus. Goals of this effort include doubling the fuel economy of buses currently in service and reducing emissions to 1/10 of EPA standards.

Fuel-Efficient Buses

A government, industry, and academic cooperative is developing an advanced hybrid electric city transit bus. Goals of this effort include doubling the fuel economy of buses currently in service and reducing emissions to one tenth of EPA standards.

Enhanced Video Images

The new NASA software, VISAR, can make valuable clues visible in videos taken in low light. The single frame image (left) taken at night was brightened, enhancing both details and noise, or "snow." Then, to further overcome the video defects in one frame, VISAR adds information from multiple frames to reveal a person. To create the clarified image (right), 50 frames of video—which is less than one second on videotape—were added together.

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Notes

